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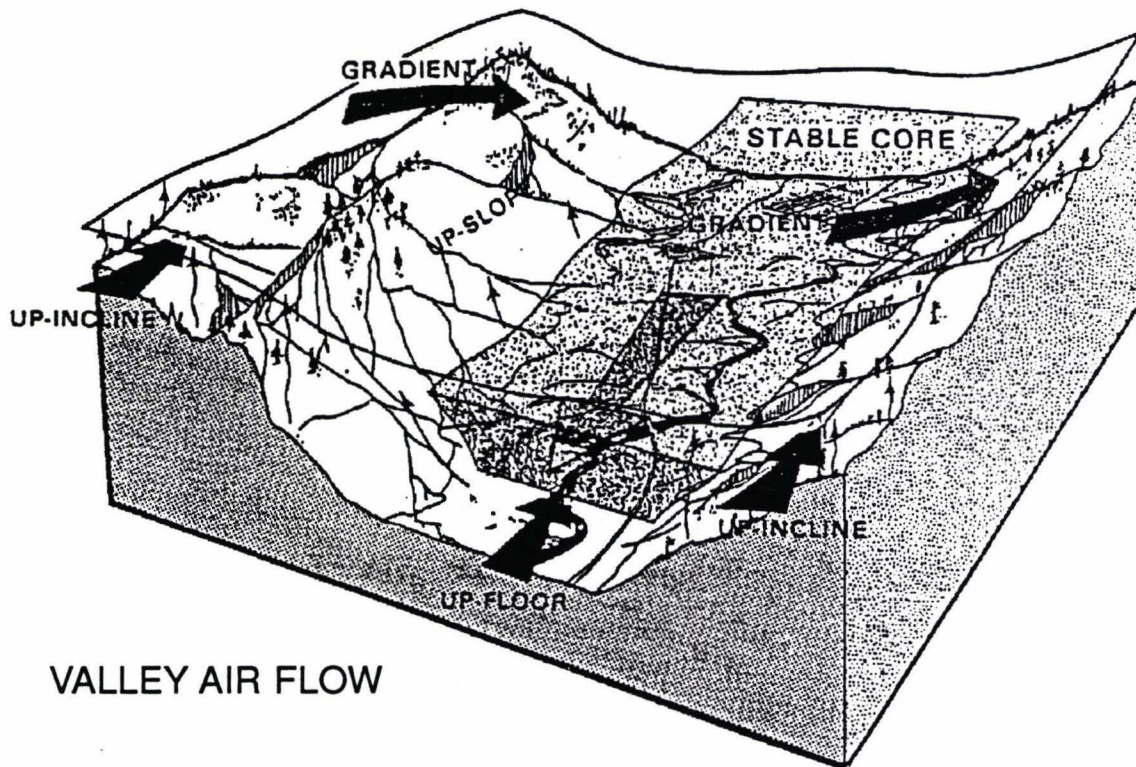
Forest Service



Forest Pest
Management

Davis, CA

TECHNICAL SPECIFICATION DOCUMENT FOR A VISUALIZATION MODEL THAT SIMULATES SPRAY PLUME DISPERSION OVER COMPLEX TERRAIN



VALLEY AIR FLOW

FPM 90 - 5
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TECHNICAL SPECIFICATION
DOCUMENT FOR A
VISUALIZATION MODEL
THAT SIMULATES SPRAY
PLUME DISPERSION OVER
COMPLEX TERRAIN

Prepared by:

John E. Heasley
Resource Analysis Systems
333 West Drake Rd.
Ft. Collins, CO 80526

Under PO 40-82FT-O-0644
USDA Forest Service
Rocky Mountain Experiment Station

Prepared for:

USDA Forest Service
WO/FPM Methods
Application Group
Ft. Collins, CO
and
WO/FPM Pesticide-
Use Management and
Coordination Staff
Davis, CA

Project Officers:

William B. White
John W. Barry

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PREFACE

The USDA Forest Service, Forest Pest Management is developing a computer-based system called the Integrated Forest Resource Management System (INFORMS). The objective of INFORMS is to integrate computer-based tools commonly used by resource managers into a single, user friendly environment, thereby allowing the resource specialist to focus on problem solving, rather having to become an expert in a number of disassociated tools. INFORMS integrates resource, pest and spatial models, geographic information systems, database management systems and expert systems into a single environment. INFORMS also provides the capability to display, three dimensionally on a color display monitor, existing forest condition and the results of various actions and model predictions.

Forest Pest Management is also supporting another special study to enhance two aerial spray models (AGDISP and FSCBG) to include consideration of aerial spray dispersion over complex terrain. As particulates are released into the atmosphere from either point or elevated line sources, spray dispersion and drift are subject to atmospheric conditions and topography. It is important for resource managers to be able to view the results of these enhanced model predictions on a three dimensional, color display. Because these display capabilities exist within INFORMS, it was decided by the Aerial Spray Model Advisory Committee that a cooperative effort between INFORMS and spray model developers would speed the development effort. The technical specifications described in this report were developed at the recommendation of the Forest Pest Management Spray Model Advisory Committee during its initial meeting held December 19-20, 1989, in Fort Collins, Colorado.

SECTION 1

INTRODUCTION

Forest Pest Management is tasked with the management of pests and diseases affecting the nation's forests. Part of this job involves the suppression of pest activity through aerial spraying of insecticides. Knowledge of the behavior of the spray plume after release from the aircraft is critical to achieving control objectives and conducting an effective and safe operation. Models have been developed to predict the dispersal and deposition of the spray plume over flat terrain (Bilanin, A.J. et al. 1989, Rafferty and Bowers 1989, Teske 1989). Less information, however, is available for spray plume dispersal over complex or mountainous terrain. The objective of the work performed under this purchase order is to develop technical specifications for a software package that will elucidate the atmospheric physics principles that underlie the behavior of spray plumes in complex terrain. The purpose of this software package is to enhance the visualization of the affects of atmospheric phenomena on spray plume behavior through the use of conceptual atmospheric physics models and a visualization model. The conceptual models will illustrate the principles through graphics and text while the visualization model simultaneously depicts the spray plume behavior in mountainous terrain. This package can serve as both a briefing and training aid for Forest Pest Management. In the future the conceptual models may be replaced by actual spray plume dispersal simulation models that will in turn drive the visualization model.

ATMOSPHERIC PHYSICS OVER COMPLEX TERRAIN

Most of the research investigating atmospheric phenomena over complex terrain has been concerned with the dispersion of air pollution from a point source (Allwine and Whiteman 1988, Bader and Whiteman 1989, Doran et al. 1987, Muller and Whiteman 1988, Whiteman 1982, Whiteman and McKee 1982, Whiteman and Allwine 1985, Whiteman and Barr 1986, Whiteman et al. 1989). This work, however, has conceptual utility for describing the behavior of spray plumes under similar conditions. Consultation regarding the atmospheric physics processes occurring over mountainous terrain has been provided by Dr. C.D. Whiteman of the Battelle Pacific Northwest Laboratory. The following background information has been excerpted from his report on air pollution dispersion in mountain valleys (Whiteman and Allwine 1985).

Nocturnal Valley Meteorology

The most universal features of nighttime valley meteorology, reported in valleys all over the globe ... is the drainage of cooled air down the valley sidewalls and valley axes. The initiation of these flows, which is closely related to changes in the temperature structure above valley surfaces, has received inadequate study to date. After the short (2 to 4 hour) initiation period, the down-valley flows become well-established through the valley depth, and attain a speed that is characteristic of the valley and is reasonably steady-state. Observations (Whiteman 1980, Whiteman and McKee 1981) show that the strength of the down-valley flows is quite variable from valley to valley, and no model is yet available which can accurately predict their strengths in individual valleys. In Colorado's valleys, however, observations show that windspeeds on a clear undisturbed night in one season are typical of windspeeds on similar nights in other seasons. Observations thus seem to be the best way of specifying down-valley system strength.

Down-slope flows on the valley sidewalls become weaker and less organized after the valley inversion develops, since air flowing down the slopes must work against a very stable ambient stratification. Slope flows can more easily become detached from the sidewalls during this period, providing an important stirring mechanism which causes enhanced horizontal diffusion of pollutant plumes within the valley inversion. The effects of terrain roughness and mechanically generated turbulence also play an important role in enhancing dispersion in the down-valley flows.

Pollutant concentrations can be strongly affected by dilution of the plume due to clean air flowing in from valley tributaries. This feature of meteorology, unique to valleys, can make substantial changes in pollutant concentrations, especially where high volume fluxes of clean air are involved.

Valley Meteorology During the Temperature Inversion Breakup Period

Observation in Colorado's deep valleys (Whiteman 1980 and 1982) have provided detail on the changes in atmospheric structure during the morning transition period when the nocturnal down-valley flows are reversed to daytime up-valley flows. The transition period is much longer than expected in these deep valleys and the physical processes leading to the transition are expected to be of great importance for air pollution transport and dispersion. This section summarizes observations of inversion destruction, pointing out typical characteristics of the meteorology of these valleys, and the physical processes that must be included in a realistic simulation of the inversion destruction period.

At sunrise nocturnal inversions in most of the valleys were built up to about the level of the surrounding ridgetops. The average depth, based on 21 case studies, was 604 meters. Vertical potential temperature gradients within the inversions averaged

0.0295 degrees Kelvin / meter, but ranged from 0.0187 to 0.0566 degrees Kelvin / meter. The strength and direction of prevailing winds aloft, as determined from the morning rawinsonde sounding over Grand Junction, Colorado, had no demonstrable effect on the characteristics of valley inversions in the study. The valley inversions showed much less variability from day to day and from season to season than inversions over Grand Junction. This suggests that at least for a narrow range of conditions over a wide area, valley topography produces more consistent inversions, perhaps by protecting them from winds aloft.

When the along-valley winds were weak, the valley vertical potential temperature profiles frequently were hyperbolic in shape, especially near the ground. In most valleys where along-valley winds were of at least moderate strength, the inversion profiles were nearly linear with height.

Temperature inversions in all of the valleys investigated were destroyed after sunrise following one of three patterns of temperature structure evolution (Figure 1). The first pattern, observed in the widest valley studied, approximates inversion destruction over flat terrain, in which the nocturnal inversion is destroyed after sunrise by the upward growth from the ground of a warming convective boundary layer (CBL). The second pattern, observed in snow covered valleys, differs significantly from the first. Here the growth of the CBL, which begins after sunrise, is arrested once the CBL has attained a depth of 25 to 50 meters. The inversion is then destroyed as the top of the nocturnal inversion descends into the valley. Successive profiles of the valley atmosphere show a warming consistent with a simple subsidence of the previous profiles. The third pattern of temperature structure evolution was observed in all the valleys when snow cover was not present and describes the majority of case studies observed in field experiments. Following this pattern, inversions are destroyed by two processes: the continuous upward growth from the valley floor of a warming CBL and the continuous descent of the top of the nocturnal temperature inversion. Warming of the elevated inversion layer above the CBL is consistent with a simple subsidence of the previous profiles. In the Colorado valleys studied, the time required to break an inversion and establish a neutral atmosphere within the valley was typically 3-1/2 to 5 hours after sunrise. Temperature structure evolution during clear, relatively calm weather was surprisingly uniform from day to day and season to season. Thus, in future work, one may be fairly confident of observing typical inversion breakup during short field studies in relatively calm weather.

The common element of all three patterns of temperature structure evolution is the development of a CBL over the valley floor after it is illuminated by direct sunlight. Observations taken from the sidewall of one valley also show the development of a CBL after direct sunlight illuminates the sidewall. Due to the shading effects of surrounding topography, the different valley surfaces can be illuminated at significantly different times, thus

affecting the initiation of CBL growth. The temperature structure of the sidewall CBL is similar to that of the CBL over the valley floor, but winds blow up the sidewall CBL at speeds of up to 3 meters per second.

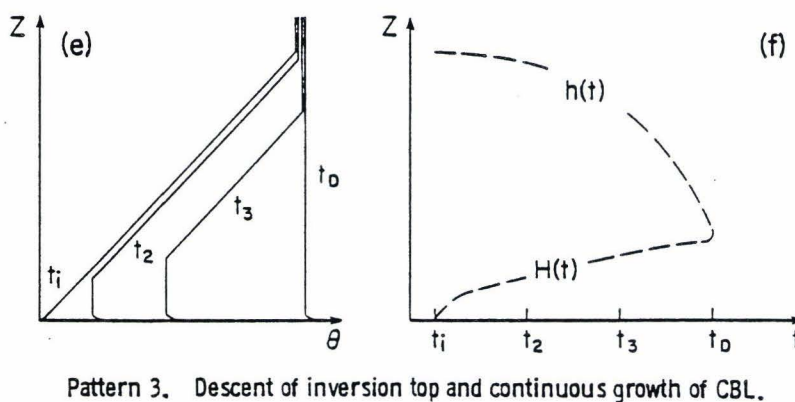
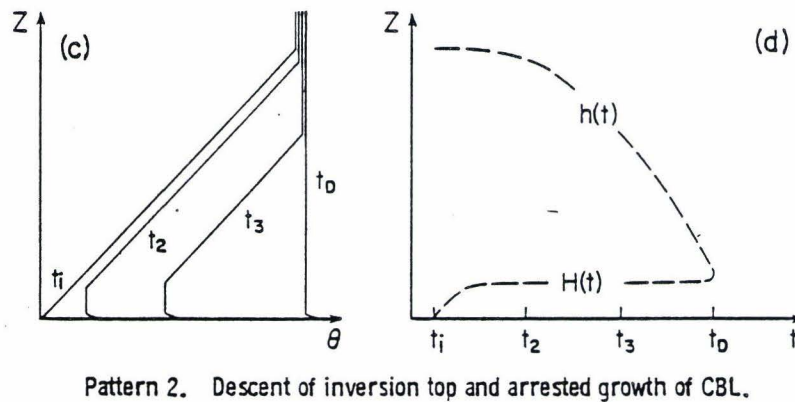
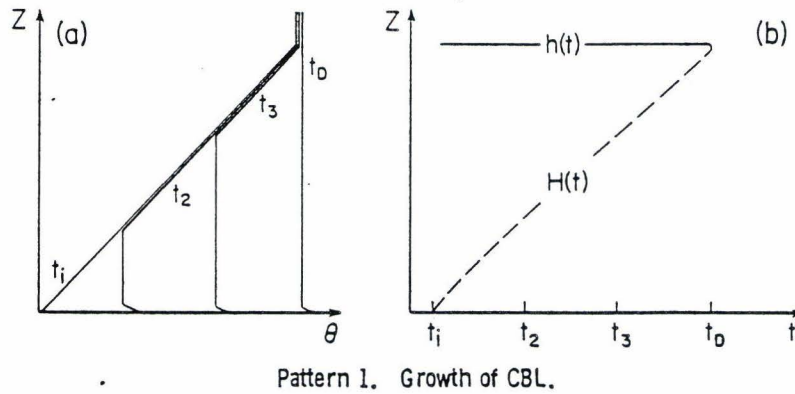


Figure 1. Three patterns of temperature structure evolution during the inversion breakup period. Potential temperature profiles are on the left, and time-height analysis of CBL height (H) and inversion top height (h) are on the right.

Five different temperature structure layers have been observed during the inversion destruction period. Above the valley floor CBL and the sidewall CBL just mentioned is the stable core of the potential temperature inversion. A neutral stability layer above the stable core appears to be part of a large-scale convective boundary layer that forms over the western slope of the Rocky Mountains. Above this layer is the free atmosphere.

Each of the five temperature structure layers, identified primarily by their potential temperature structure, can also be identified by the winds that prevail within them (see Figures 2, 3, and 4). During inversion destruction, the CBLs over the valley

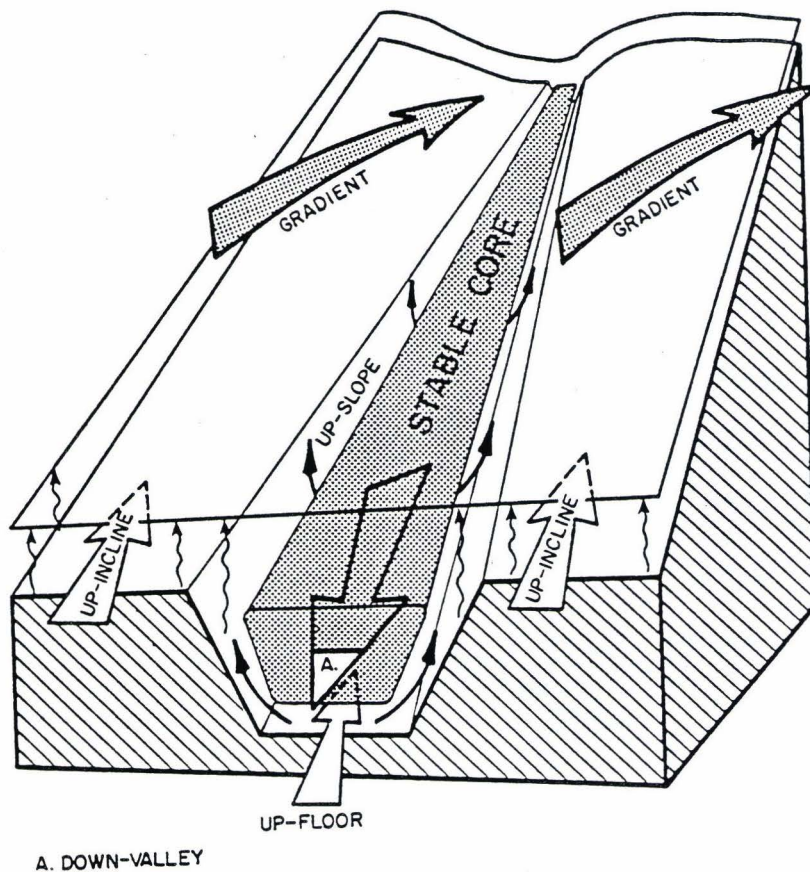


Figure 2. Typical mid-morning wind structure over and within a deep valley on the western slope of the Rockies, illustrating five interrelated wind systems identified in field studies.

floor and sidewalls contain winds which blow up the floor of the valley and up the slopes. The CBL, or neutral layer, above the valley inversion has winds which blow up the inclined Western Slope of the Rocky Mountains during the day. Winds in the stable core

typically continue to blow down-valley after sunrise until the stable core is nearly destroyed. Winds in the stable free atmosphere may blow from any direction with speeds determined by

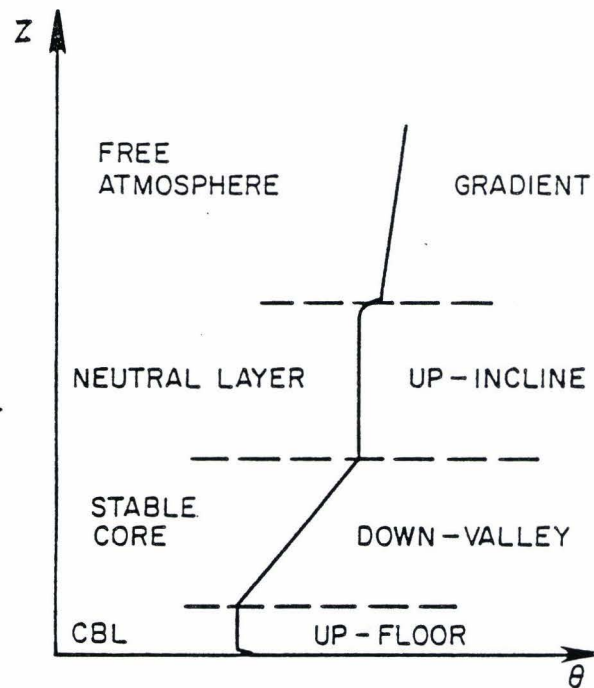


Figure 3. Relationship between temperature structure layers and wind systems. The temperature profile is a typical mid-morning sounding from the floor of a deep valley.

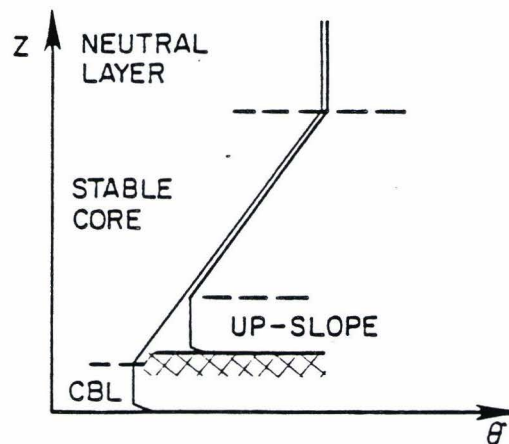


Figure 4. Dual soundings from a valley floor and a valley sidewall illustrating the upslope flow found within the CBL over the sidewall.

wide area pressure gradients. Despite variability in the strength and timing of reversal of the winds, the temperature structure evolved uniformly from day to day in individual valleys.

On the basis of the wind and temperature observations summarized above, a hypothesis (Figure 5) has been developed to explain the temperature structure evolution. Since energy is required to change the temperature structure, and the changes begin at sunrise, it is reasonable to hypothesize that solar radiation is the driving force. A fraction of the solar radiation, received on the valley floor and sidewalls, is converted to the sensible heat flux that provides energy to the valley atmosphere. Sensible heat flux from surface, as over flat terrain, causes a convective boundary layer to develop over the surface. Mass and heat are entrained into the CBL from the stable core above. Mass entrained into the valley floor and sidewall CBLs, however, is carried from the valley in the upslope flows that develop in the convective boundary layers over the sidewalls. This removal of mass from the base and sides of the stable core causes the elevated inversion to sink deeper into the valley and to warm adiabatically due to subsidence, and decreases the rate of growth of the CBLs. Following this hypothesis, the rate of warming depends directly on the rate of energy input into the valley atmosphere. This energy may be used to deepen the CBLs or to move mass up the sidewalls, allowing the stable core to sink. From this hypothesis a thermodynamic model of temperature inversion destruction has been developed (Whiteman and McKee 1982).

The valley inversion destruction mechanism has important implications for the dispersion of valley air pollution. Many of the same principles apply to spray plume dispersion at different application sites within the valley. Investigation of these implications for air pollution assumes that the nocturnal inversion at sunrise contains pollutants emitted from a continuous elevated source within the valley. During the night such pollutants would be carried down the valley in the along-valley wind system, undergoing both vertical and horizontal dispersion. The horizontal dispersion in these flows is known to be much greater than over flat terrain. After sunrise a convective boundary layer forms over the valley floor and sidewalls (Figure 6a). The subsequent disposition of pollutants in the stable core will be affected by two competing processes--the sinking of the stable core and the growth of the CBL. The air pollution implications of the two processes can be considered by studying a valley cross section down-valley from the source at a later time. The three inversion breakup patterns discussed above have the following air pollution implications:

1. Pattern 1 - Growth of convective boundary layer (Figure 6b): Pure growth of a CBL will result in fumigation of pollutants at the valley floor as the CBL grows upward into the polluted stable core. This process is favored when the slope flows are ineffective in removing mass from a valley, and thus will occur in very wide or shallow valleys.
2. Pattern 2 - Sinking of stable core (Figure 6c): Failure

of the CBL to grow once it has formed over the valley

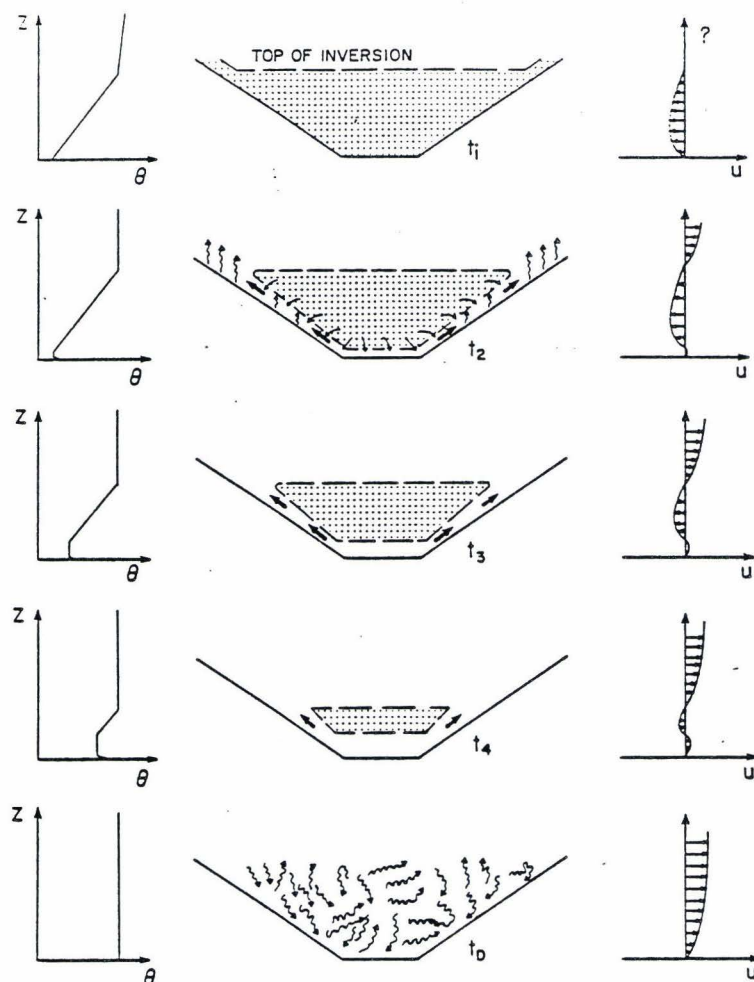


Figure 5. Illustration of the hypotheses of inversion destruction. In the center of the diagram cross sections of a valley are shown at times t_1 , t_2 , t_3 , t_4 , and t_D . On the left are corresponding potential temperature profiles as taken from the valley center. On the right are corresponding up-valley wind components as a function of height. At sunrise, t_1 , an inversion is present in the valley. At t_2 , a time after sunlight has illuminated the valley floor and slopes, a growing CBL is present over the valley surfaces. Mass and heat are entrained into the CBLs from the stable core above and carried up the sidewalls in the upslope flows. This results in a sinking of the stable core and growth of the CBLs (t_3 and t_4) until the inversion is broken (t_D) and turbulent well-mixed neutral atmosphere prevails through the valley depth. Down-valley winds continue to blow in the stable core during the inversion breakup period. Winds in the CBL below, and in the region above the stable core often blow up-valley during this same period.

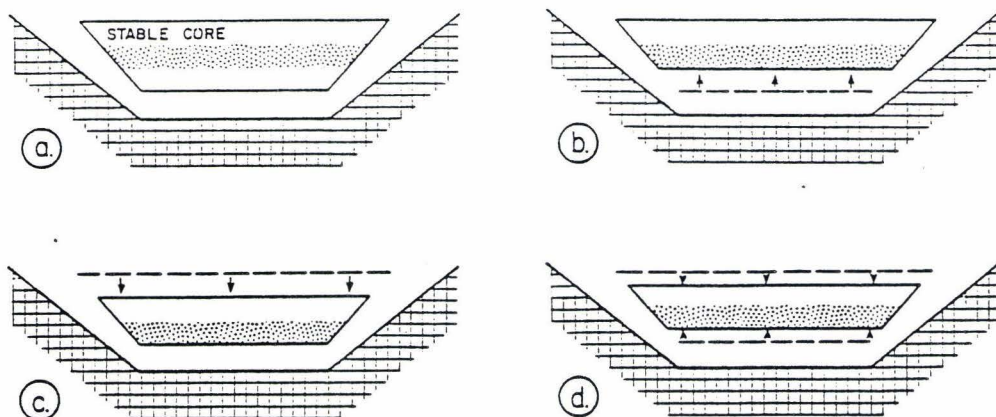


Figure 6. Air pollution implications of CBL growth and inversion top descent.

floor and sidewalls results in inversion destruction by sinking of the stable core. Thus, the pollutants sink into the top of a shallow mixed layer, producing high concentrations at the ground. The pollutant plume, once entrained into the CBL, is advected up the sidewalls and dispersed into the neutral layer aloft. This process is favored for narrow-to-wide valleys when sensible heat flux is weak.

3. Pattern 3 - Combination (Figure 6d): A combination of CBL growth and stable core descent results in the sinking of pollutants into the top of a growing mixed layer. Pollution concentrations should be intermediate between the previous two cases. This pattern is the most common one in Colorado mountain valleys.

Another process, that of cross-valley advection of the pollutant plume due to differential heating of the valley sidewalls, may be important in determining the cross-valley position of maximum pollutant concentration. Unfortunately, relatively little observational evidence is presently available on cross-valley advection or the effects of cross valley advection on pollutant dispersion.

Observations in snow-free valleys of Colorado show that inversions are typically destroyed within 3-1/2 to 5 hours after sunrise, regardless of season. Thus, high pollutant concentrations at the ground may be expected following sunrise in polluted Colorado valleys. But inversions are typically broken every day and, once the inversion is destroyed, good mixing will prevail in an up-valley flow regime that is coupled to flows above the valley.

Moist surface conditions or high albedo due to snow cover may change the surface energy budget components so that sensible heat

flux is reduced. In these conditions inversion destruction will be delayed or an inversion may persist all day. In Colorado's snow-covered Yampa Valley on February 28, 1978, the CBL failed to grow deeper than 35 meters and the observations were characterized by a slow descent of the stable core (Whiteman 1980). The inversion failed to break during this day, although the top of the stable core descended to within 150 meters of the ground.

To summarize, the primary factors affecting a valley pollutant plume after sunrise are:

- continued transport of the pollutant plume down the valley in the stable core
- sinking motions in the stable core as inversion destruction progresses after sunrise, bringing the plume closer to the valley floor
- fumigation of the plume into convective boundary layers growing over the valley floor and sidewalls
- transport and diffusion of pollution in upslope flows that develop over the sidewalls.

These processes continue from sunrise until the valley temperature inversion is destroyed and the valley atmosphere becomes coupled with the overlying circulations. The amount of time required for temperature inversion destruction in the Colorado Mountain Valleys is typically 3-1/2 to 5 hours, but it depends on many factors including the depth and strength of the initial temperature inversion, the incoming solar energy, the sensible heat flux, the pattern of inversion destruction followed, etc.

SECTION 2

TECHNICAL DESIGN

System Description

The objective of the software package described below is to enhance the visualization of the affects of atmospheric phenomena on spray plume behavior through the use conceptual atmospheric physics models and a visualization model. The conceptual models will illustrate the principles through graphics and text while the visualization model simultaneously depicts the spray plume behavior in mountainous terrain. The design will be similar to a mountain pine beetle demonstration package developed for the Methods Application Group of Forest Pest Management (see Appendix A). The software will be written in the C language and operate on an IBM compatible personal computer with a VGA graphics card.

The system will consist of a main program module and two submodules. The main module will display the program banner, an opening narrative and the main options menu. There will be five options available to the user. These include an atmospheric physics tutorial and four spray scenarios. The spray scenarios to be presented are:

- release of the spray in the stable core center
- release of the spray over the sunny sidewall above the inversion layer
- release of the spray over the sunny sidewall below the inversion layer
- release of the spray over the shady sidewall.

The atmospheric physics tutorial module will present principles operating at four different times of the day. The opening screen will consist of drawings depicting atmospheric conditions before sunrise, at sunrise, mid morning and late afternoon (Figure 7). Using a mouse or cursor keys the user will select the time period that he/she is interested in by locating the cursor over the appropriate drawing and clicking the mouse or pressing <ENTER>. A new screen will be displayed that shows wind (Figure 8) and temperature conditions (Figure 9) for that time period. The wind graphics will be superimposed on an actual terrain scene of the valley and be accompanied by a narrative explaining the phenomena and its significance for spray operations.

The user will select a spray scenario to see the effects of valley atmospheric physics on spray plume behavior. For each scenario a series of screens depicting spray plume behavior over time will be displayed. Each screen will contain a map showing the horizontal position of the spray plume, a perspective view showing the three dimensional position of the spray plume and a three

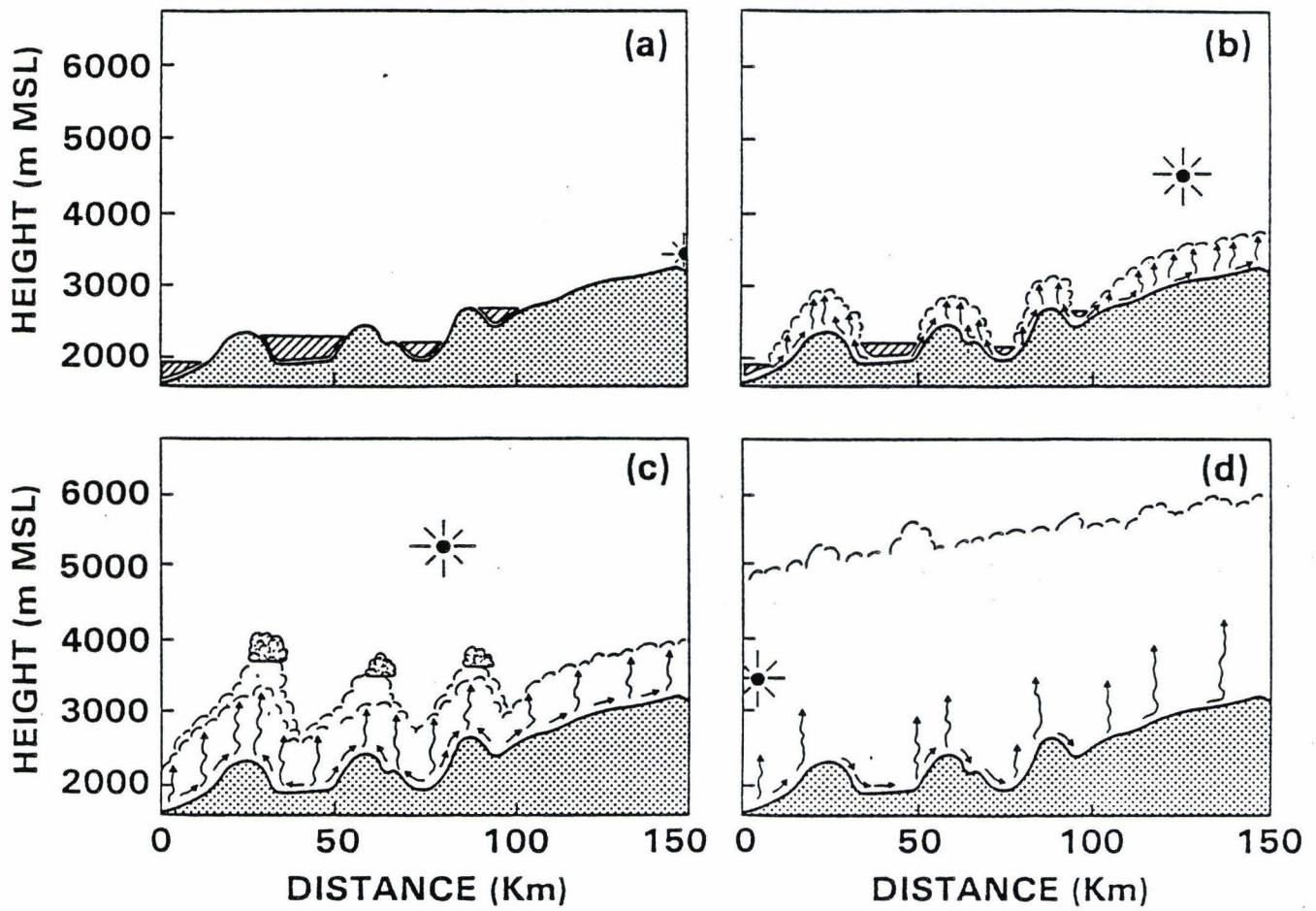


Figure 7. Graphics screen depicting atmospheric conditions at four times of day.

VALLEY AIR FLOW

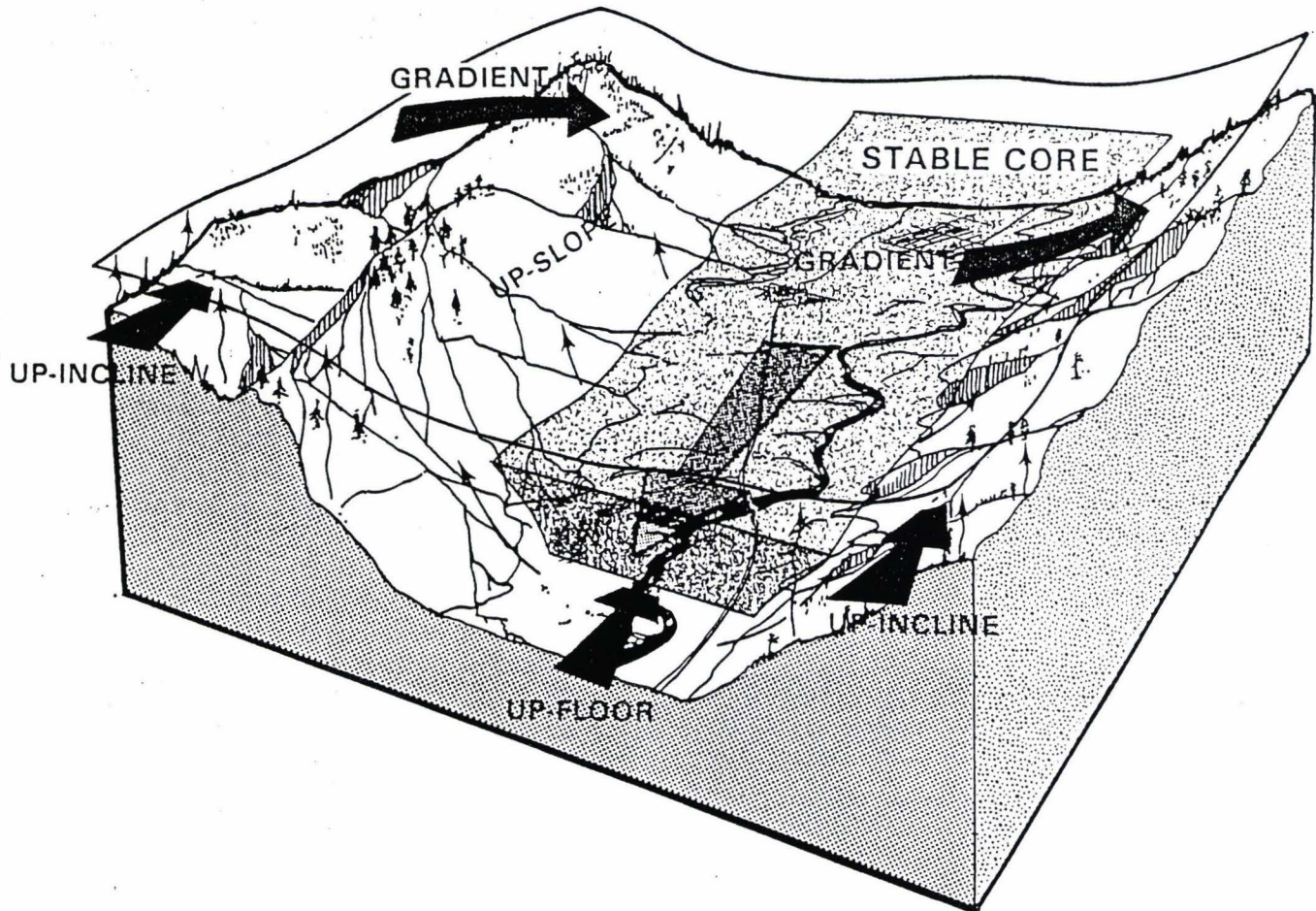


Figure 8. Wind graphics over complex terrain at sunrise.

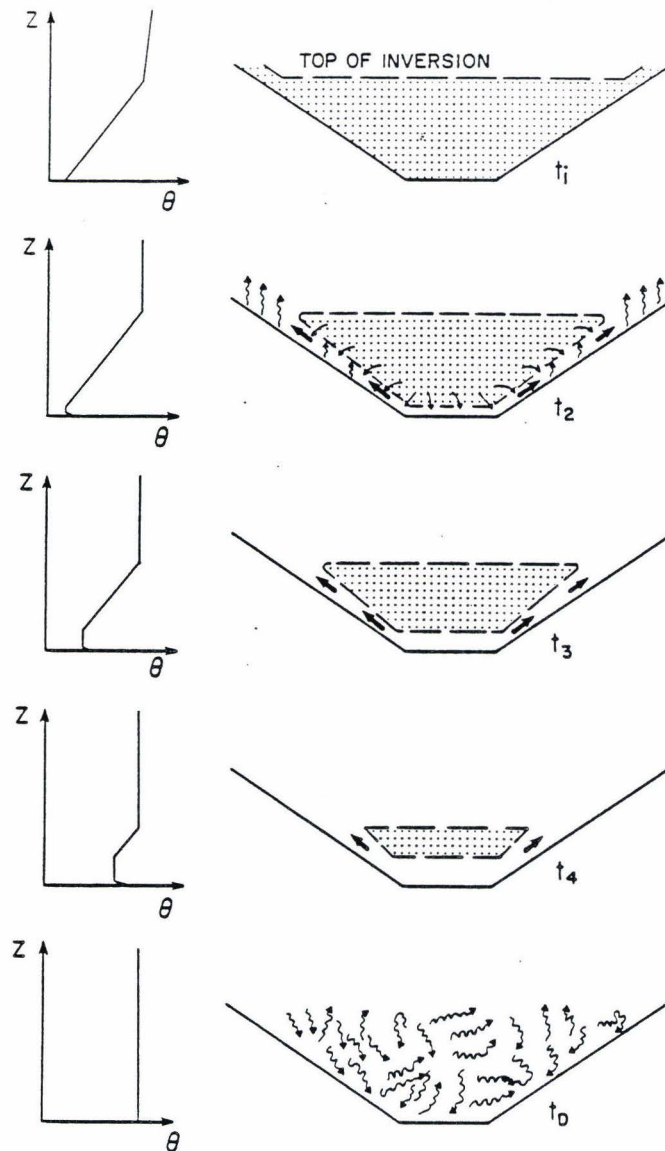


Figure 9. Changes in the temperature profile during the morning inversion breakup.

dimensional graphic illustrating the underlying atmospheric physics at that point in time. Each screen will also contain a narrative that will relate the physical phenomena to the behavior shown. Spray deposition will also be depicted. The user will also have the option of displaying the time history of the plume behavior by displaying all of the perspective scenes or all of the maps on the same screen. The same type of screens will be repeated for each of the other scenarios. Appendix A shows some examples of perspective

scenes and maps for the mountain pine beetle demonstration. The spray plume package will be similar in nature.

Figure 10 shows a functional block diagram for the system. The main interface module will perform the following functions:

- display the program banner page and introductory narrative
- display the main menu and allow selection of options
- invoke the atmospheric physics tutorial module
- invoke the visualization module

Selection of the atmospheric physics tutorial option will invoke the tutorial module. This module first displays the main graphics screen (see Figure 7) and allows option selection of the atmospheric conditions to be explained via a pointing device such as a mouse. This will be performed by the graphic input function. The screen control module determines which graphics and text will be displayed and passes that information on to the screen generator. The screen generator retrieves the appropriate graphic images and text and builds a screen to illustrate the atmospheric phenomena for the time of day selected.

When a spray scenario is selected from the main menu, the scenario code is passed to the visualization module where a visual simulation is run for that scenario. Four slices in time will be simulated from the time the plume is laid down to its deposition and dispersion. A three dimensional perspective view as well as a planar view (over a two dimensional map) of the plume behavior will be displayed for each time slice. Graphics depicting the atmospheric physics principles involved and a narrative relating them to the plume behavior will also be provided. Each screen will be compiled and built through the screen control and generator modules.

Data Requirements

The system will require elevation data for a valley suitable for illustrating the atmospheric principles involved. The depth of the valley should be greater than 300 meters. There should be no major tributaries and should be fairly linear in shape. These criteria are designed to simplify the problem. The valley floor should be from 100 to 1000 meters wide and the sides should be forested. A north-south orientation would be best for illustrating the effects of solar heating. A stand boundary map is required with a corresponding tree inventory database. If this does not exist it can be digitized. Tree densities for four height classes for each species is needed from the inventory data.

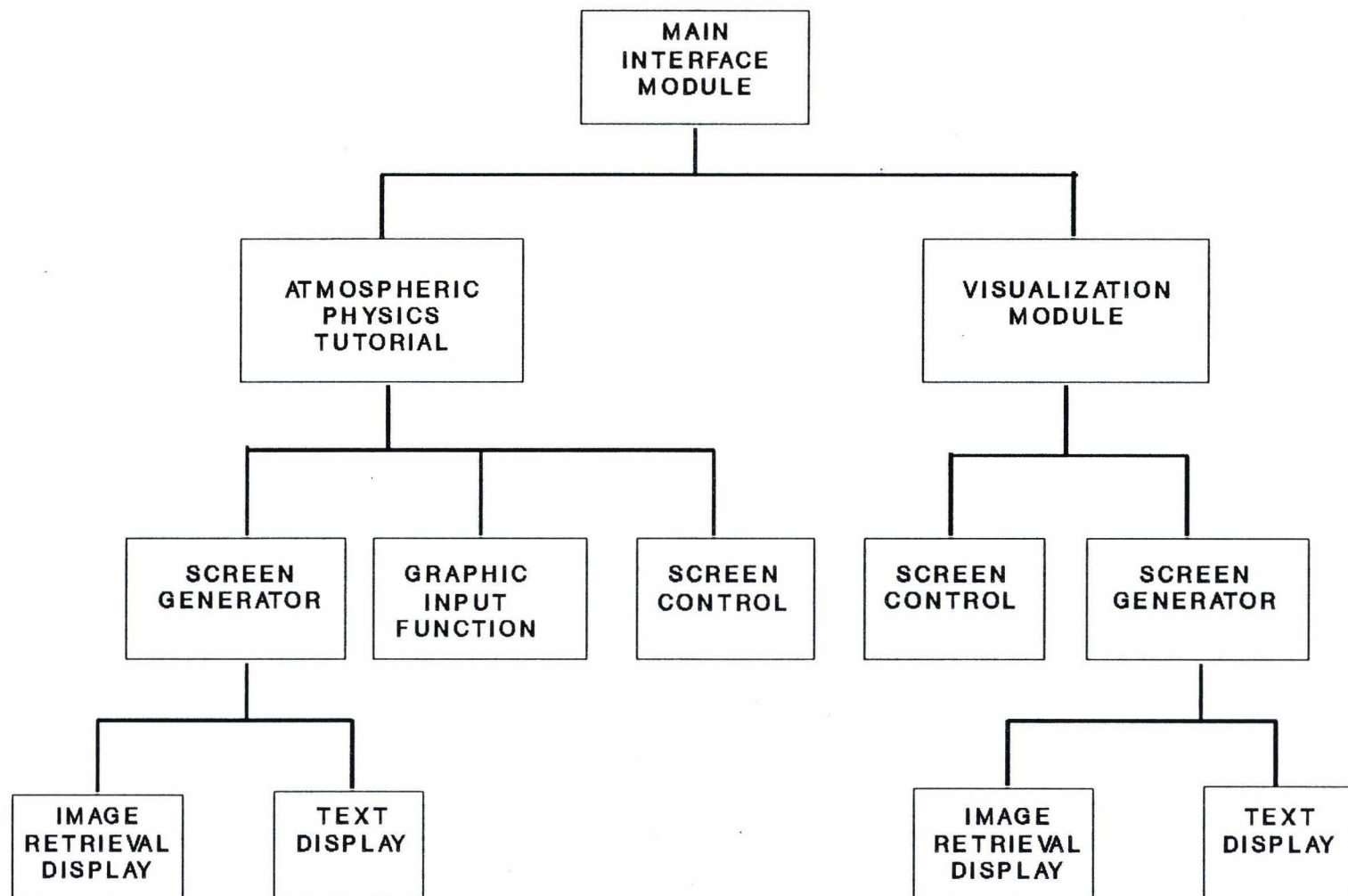


Figure 10. Spray visualization system block diagram

Tasks Required

1. Select a representative valley and gather the required data.
2. Develop techniques for displaying the spray plume in a realistic manner. This will require some research and experimentation.
3. Develop techniques for incorporating tutorial graphics with perspective terrain plots.
4. Develop techniques for simulating plume behavior in response to conceptual changes in atmospheric conditions.
5. Generate the perspective scenes from various viewpoints and viewer heights and select the ones which best illustrate the points to be made.
6. Generate the graphics for the tutorial.
7. Write the narratives for the tutorial.
8. Simulate plume behavior for each of the scenarios and generate a view scene for each time slice.
9. Review simulation results for consistency with atmospheric physics principles.
10. Generate the atmospheric physics graphics to go along with each view scene.
11. Write the narratives relating the atmospheric physics for each scenario and time slice to plume behavior.
12. Generate the maps showing plume position for each scenario and time slice.
13. Develop the program modules for the system.
14. Document the package describing the system, techniques used and assumptions made.

SECTION 3

TIME/COST ANALYSIS

The development of the software package described above requires expertise in several areas. These include:

- expertise in atmospheric physics in mountainous terrain
- expertise in insecticide plume behavior under various conditions
- expertise in digital mapping and visualization techniques
- expertise in microcomputer environments, graphics and the C language

The estimated time to complete each of the tasks is as follows:

- task 1 - 80 hours
- task 2 - 120 hours
- task 3 - 80 hours
- task 4 - 80 hours
- task 5 - 40 hours
- task 6 - 24 hours
- task 7 - 16 hours
- task 8 - 80 hours
- task 9 - 16 hours
- task 10 - 40 hours
- task 11 - 24 hours
- task 12 - 40 hours
- task 13 - 40 hours
- task 14 - 80 hours

The total estimated time to complete the project is 3-1/2 to 4-1/2 months at an estimated cost of \$28,000. to \$38,000. This includes consulting fees and travel expenses. This project requires a significant amount of experimentation and research. The conservative figure allows for the uncertainty associated with experimental work.

SECTION 4

REFERENCES

1. Allwine, K.J. and C.D. Whiteman. 1988. Ventilation of pollutants trapped in valleys: a simple parameterization for regional-scale dispersion models. *Atmospheric Environment*. vol. 22 no. 9, 1839 - 1845.
2. Bader, D.C. and C.D. Whiteman. 1989. Numerical simulation of cross-valley plume dispersion during the morning transition period. *Journal of Applied Meteorology*. vol. 28 no. 7, 652 - 664.
3. Bilanin, A.J., M.E. Teske, J.W. Barry, and R.B. Ekblad. 1989. AGDISP: The aircraft spray dispersion model, code development and experimental validation. *Transactions of the ASAE* 32(1):327-334
4. Doran, J.C., T.W. Horst and C.D. Whiteman. 1987. Wind and temperature structure on the slopes of a mountain valley. In *Proceedings of the Fourth Conference on Mountain Meteorology*, Aug. 25-28, 1987, Seattle, Washington.
5. Muller, H. and C.D. Whiteman. 1988. Breakup of a nocturnal temperature inversion in the Dischma Valley during DISKUS. *Journal of Applied Meteorology*. vol. 27 no. 2, 188 - 193.
6. Rafferty, J.E. and J.F. Bowers. 1989. Comparison of FSCBG2 and FSCBG3 aerial spray model predictions with field measurements. Report prepared for USDA Forest Service FPM. Davis, Ca. 42pp.
7. Skyler, P., J.W. Barry and J. Warner. 1989. FSCBG computer model predictions of swath widths - 1988 western spruce budworm project, Pacific Northwest Region. FPM 89-4. 26pp.
8. Teske, M.E. 1989. AGDISP comparisons with four field deposition studies. FPM 89-5. 57pp.
9. Whiteman, D.C. 1980. Breakup of temperature inversions in Colorado mountain valleys. Ph.D. Dissertation, Colorado State University, pp. 250.
10. Whiteman, D.C. and T.B. McKee. 1981. Valley wind systems under temperature inversion conditions. *Proceedings, symposium on intermediate range atmospheric transport processes and technology assessment*. October 1-3, 1980, Gatlingburg, Tennessee, pp. 351 - 358.
11. Whiteman, D.C. 1982. Breakup of temperature inversions in

deep mountain valleys: part I. observations. Journal of Applied Meteorology. vol 21 no. 3, 270 - 289.

12. Whiteman, D.C. and T.B. McKee. 1982. Breakup of temperature inversions in deep mountain valleys: part II. thermodynamic model. Journal of Applied Meteorology. vol 21 no. 3, 290 - 302.
13. Whiteman, C.D. and K.J. Allwine. 1985. VALMET - a valley air pollution model. Final Report - PNL-4728 Rev. 1. Battelle Pacific Northwest Laboratory. 176 pp.
14. Whiteman, C.D. and S. Barr. 1986. Atmospheric mass transport by along-valley wind systems in a deep Colorado valley. Journal of Climate and Applied Meteorology. vol 25 no. 9, 1205 - 1212.
15. Whiteman, C.D., K.J. Allwine, L.J. Fritschen, M.M. Orgil, and J.R. Simpson. 1989. Deep valley radiation and surface energy budget microclimates. part I: radiation. Journal of Applied Meteorology. vol. 28 no. 6, 414 - 426.
16. Whiteman, C.D., K.J. Allwine, L.J. Fritschen, M.M. Orgil, and J.R. Simpson. 1989. Deep valley radiation and surface energy budget microclimates. part II: energy budget. Journal of Applied Meteorology. vol. 28 no. 6, 427 - 437.

APPENDIX A

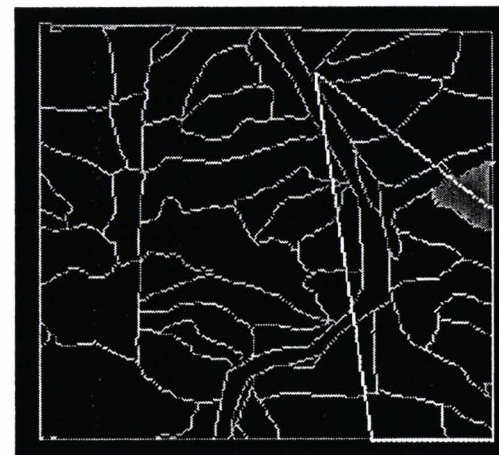
APPENDIX A

MOUNTAIN PINE BEETLE DEMO SCREENS

MOUNTAIN PINE BEETLE DEMO

PRESS RETURN TO CONTINUE

This demonstration package was created for the METHODS APPLICATION GROUP of Forest Pest Management by RESOURCE ANALYSIS SYSTEMS of Fort Collins, Colorado. The demo illustrates the impact of a simulated mountain pine beetle outbreak on the visual quality of a lodgepole pine forest in Montana. The spread of mountain pine beetle damage and its visual consequences are displayed for three treatment regimes. The view scenes were generated by a visual impact model that has been implemented within in the Integrated Forest Resource Management System (INFORMS) using digital elevation data and stand exam information. The map above shows the outbreak area relative to the observed scene area (viewshed).



■ MPB OUTBREAK
..... VIEWSHED
— STAND BOUNDARIES

PRESS RETURN TO CONTINUE

OPTIONS MENU

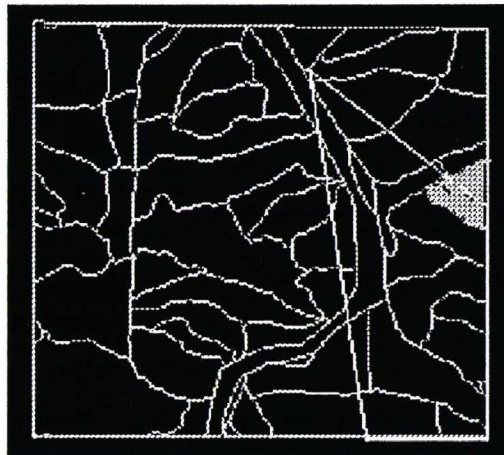
- 1 EXIT
 - 2 NO TREATMENT
 - 3 THIN SUSCEPTIBLE STANDS
 - 4 CLEARCUT
 - 5 COMPARE TREATMENTS
- SELECT:

NO TREATMENT: MPB OUTBREAK IS ALLOWED TO GO UNCHECKED
FOR TEN YEARS.

OUTPUT OPTIONS

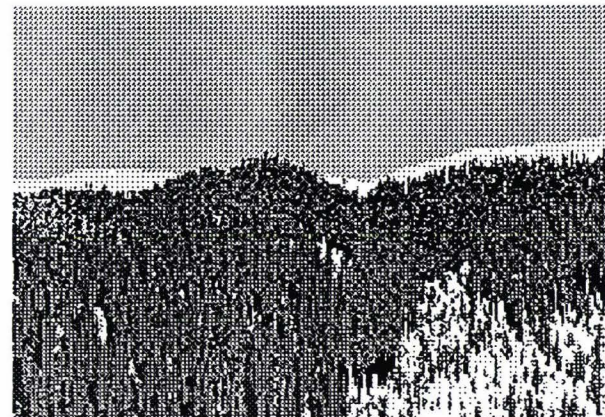
- 1 EXIT
- 2 DISPLAY SPREADMAP/VIEWSCENE FOR EACH YEAR
- 3 DISPLAY ALL SPREADMAPS
- 4 DISPLAY ALL VIEW SCENES

SELECT:

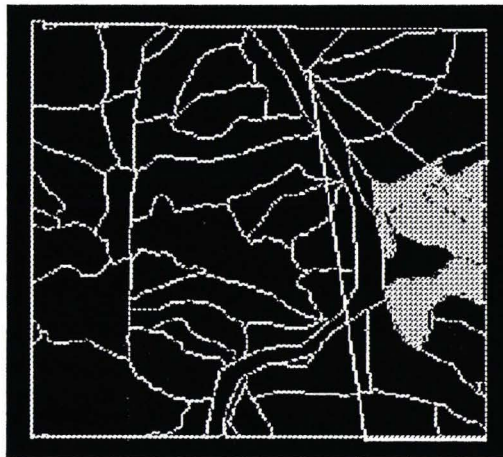


 **MPB OUTBREAK**
 **VIEWSHED**
 **STAND BOUNDARIES**

NO TREATMENT: 1990

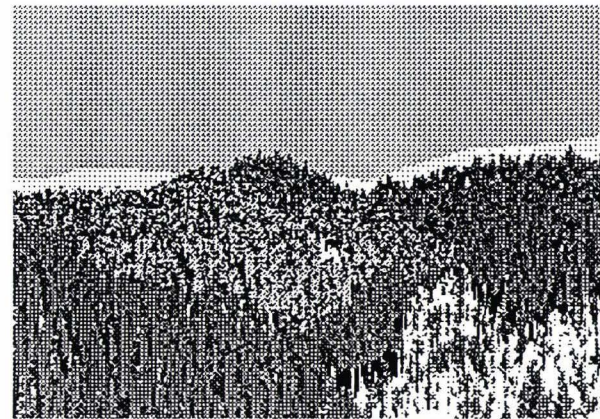


PRESS RETURN TO CONTINUE

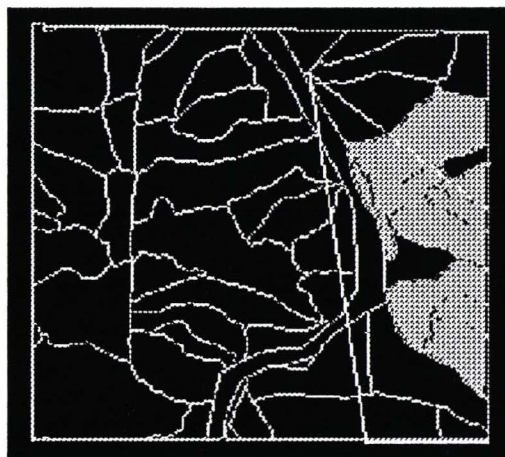


 MPB OUTBREAK
 VIEWSHED
 STAND BOUNDARIES

NO TREATMENT: 1993

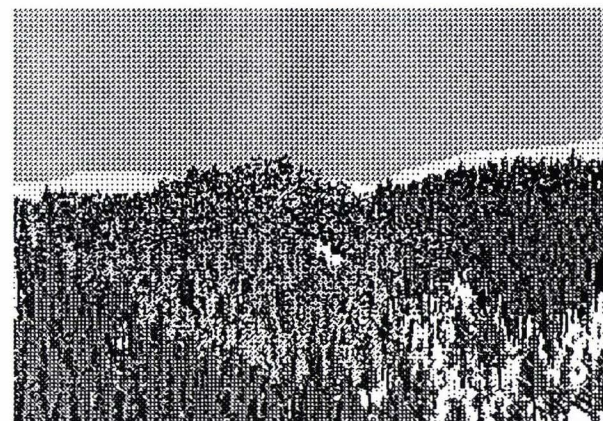


PRESS RETURN TO CONTINUE

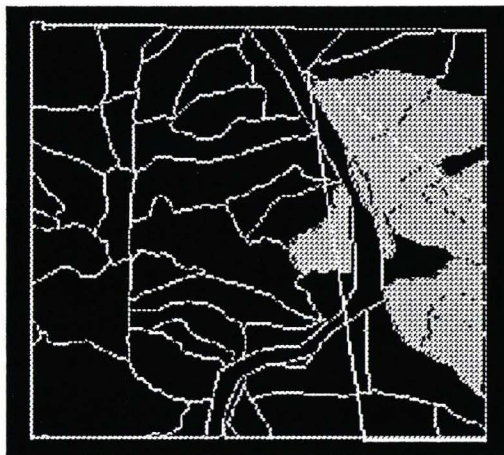


 MPB OUTBREAK
 VIEWSHED
 STAND BOUNDARIES

NO TREATMENT: 1996

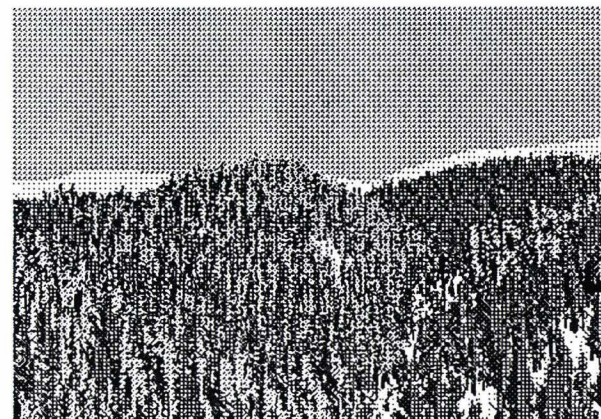


PRESS RETURN TO CONTINUE

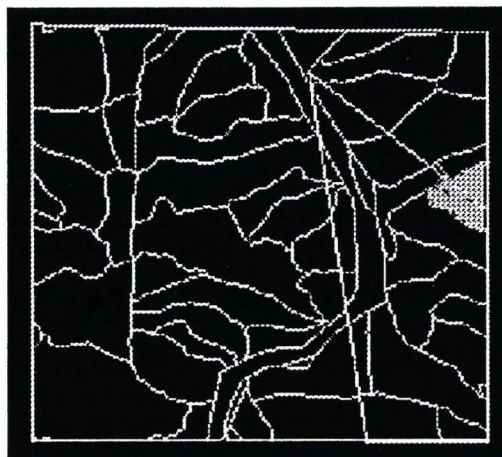


MPB OUTBREAK
VIEWSHED
STAND BOUNDARIES

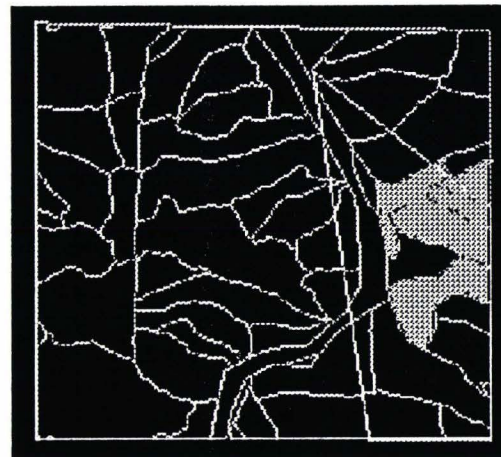
NO TREATMENT: 1999



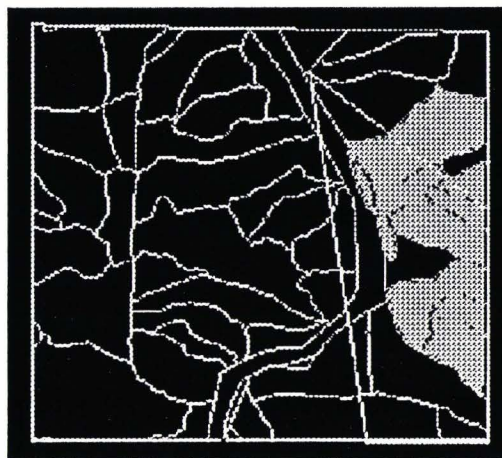
PRESS RETURN TO CONTINUE



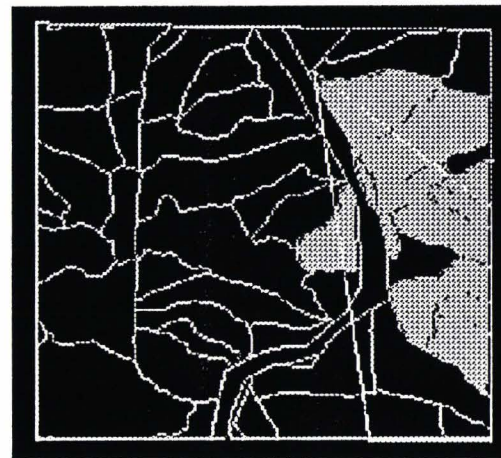
NO TREATMENT: 1990



NO TREATMENT: 1993

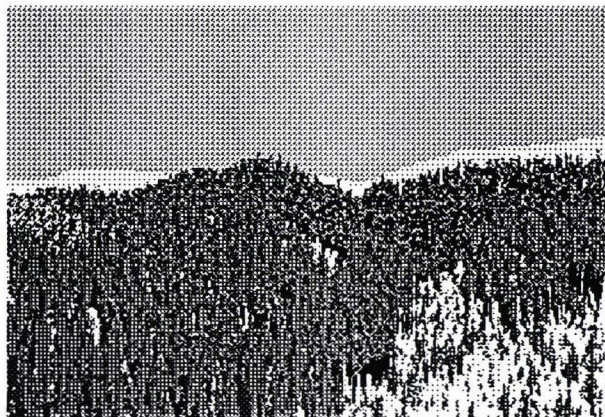


NO TREATMENT: 1996

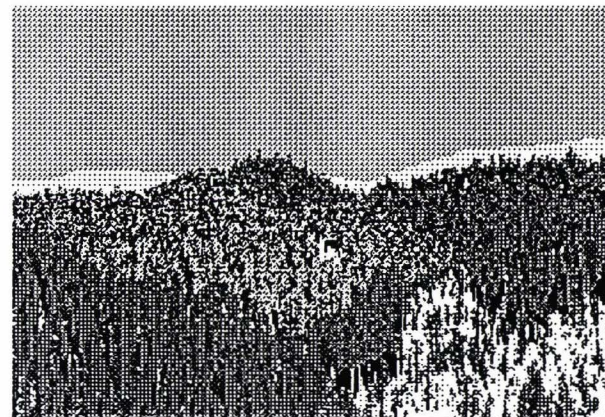


NO TREATMENT: 1999

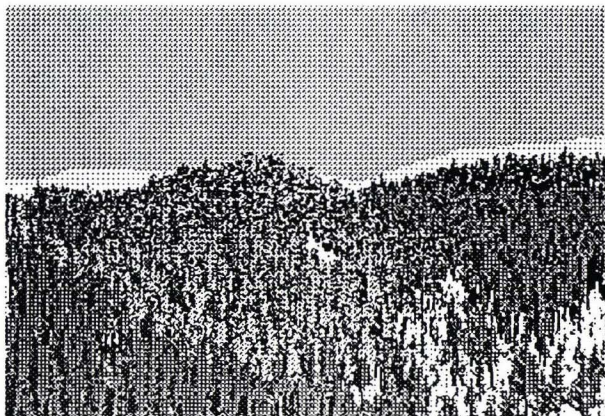
PRESS RETURN TO CONTINUE



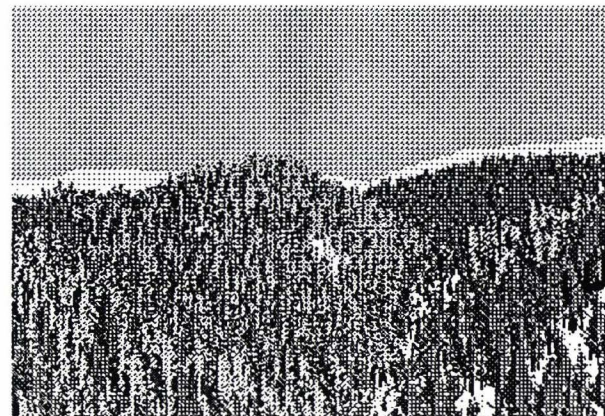
NO TREATMENT: 1990



NO TREATMENT: 1993



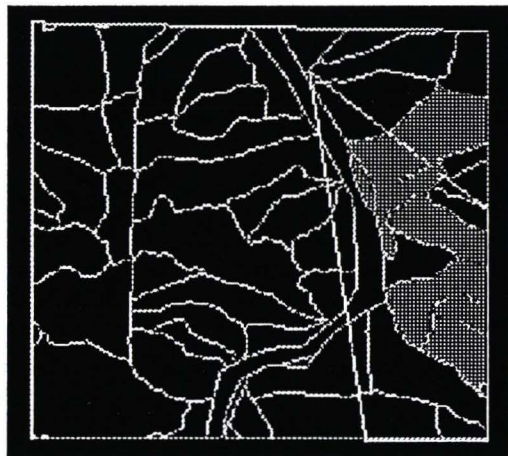
NO TREATMENT: 1996



NO TREATMENT: 1999

PRESS RETURN TO CONTINUE

THINNING: ALL SUSCEPTIBLE STANDS ARE THINNED
FROM ABOVE TO LESS THAN 50 PERCENT.

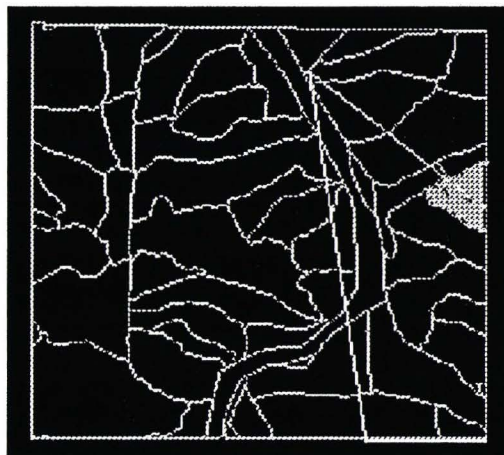


 STANDS THINNED
 VIEWSHED
 STAND BOUNDARIES

OUTPUT OPTIONS

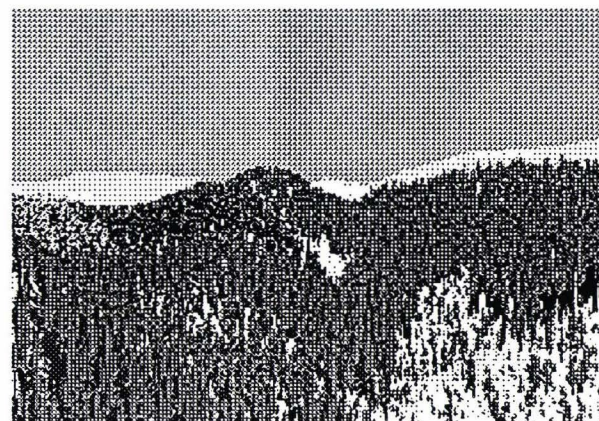
- 1 EXIT
- 2 DISPLAY SPREADMAP/VIEWSCENE/YEAR
- 3 DISPLAY ALL SPREADMAPS
- 4 DISPLAY ALL VIEW SCENES

SELECT:

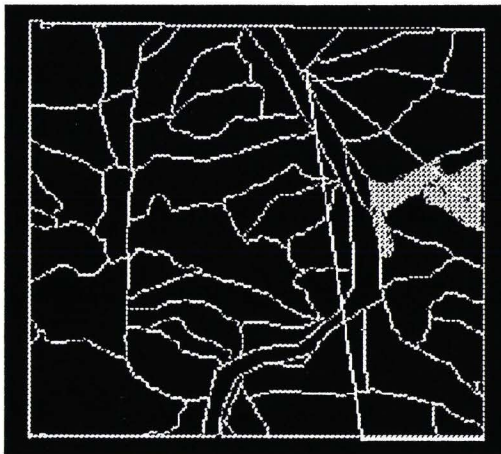


MPB OUTBREAK,
VIEWSHED
STAND BOUNDARIES

THINNING: 1990

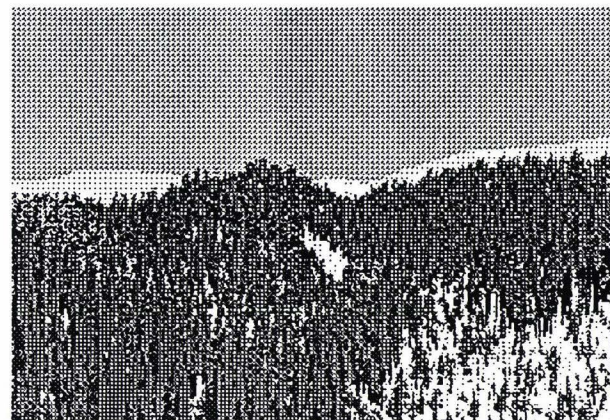


PRESS RETURN TO CONTINUE

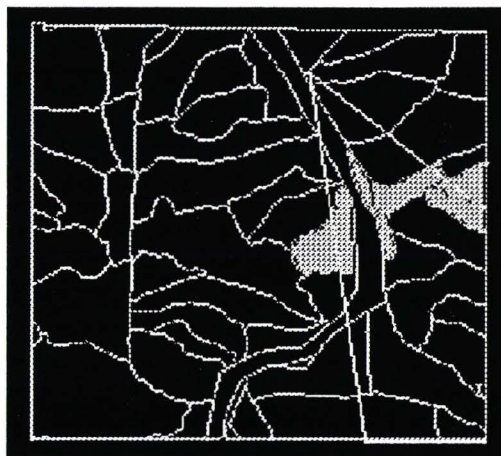


MPB OUTBREAK
VIEWSHED
STAND BOUNDARIES

THINNING: 1993

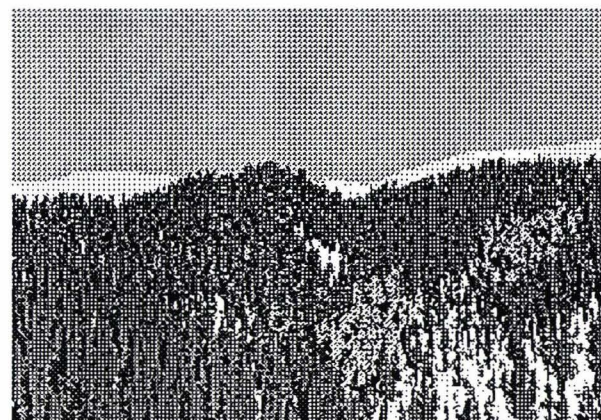


PRESS RETURN TO CONTINUE

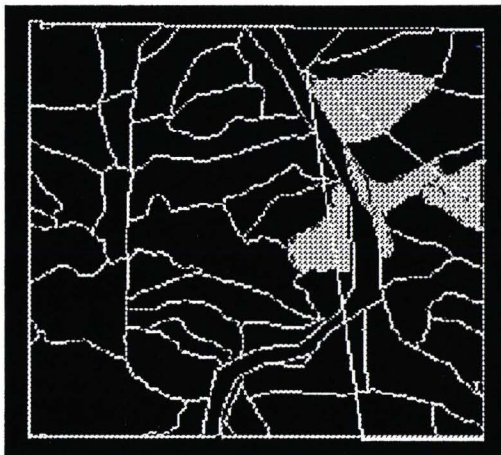


 **MPB OUTBREAK**
 **VIEWSHED**
 **STAND BOUNDARIES**

THINNING: 1996



PRESS RETURN TO CONTINUE

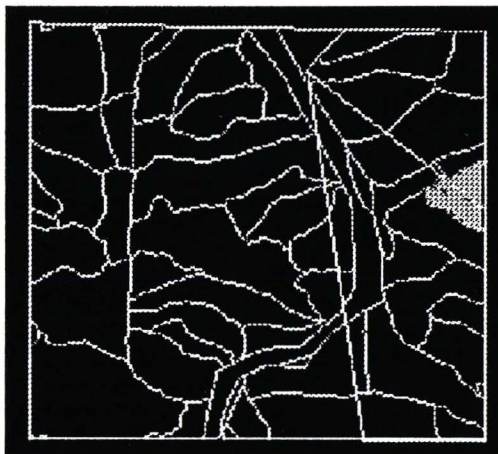


MPB OUTBREAK
VIEWSHED
STAND BOUNDARIES

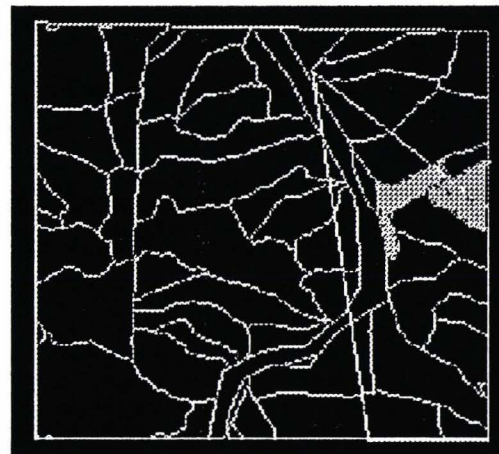
THINNING: 1999



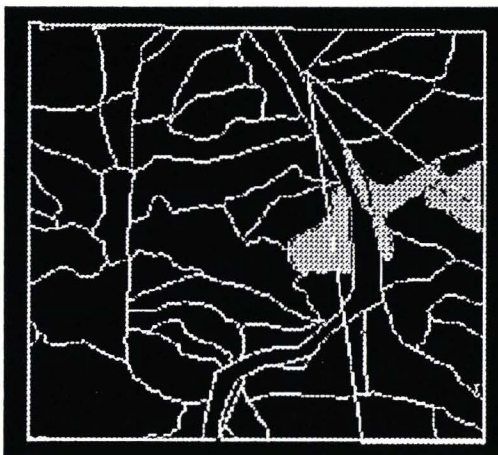
PRESS RETURN TO CONTINUE



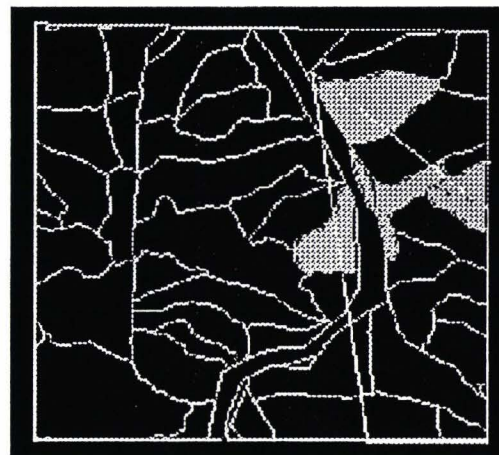
THINNING: 1990



THINNING: 1993

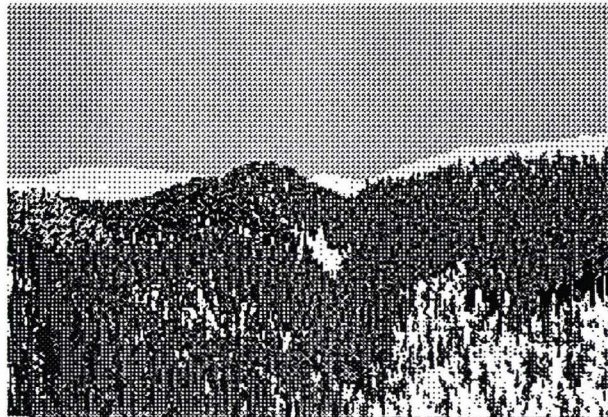


THINNING: 1996

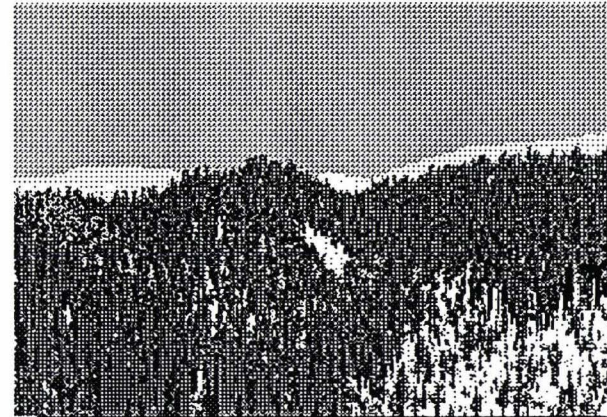


THINNING: 1999

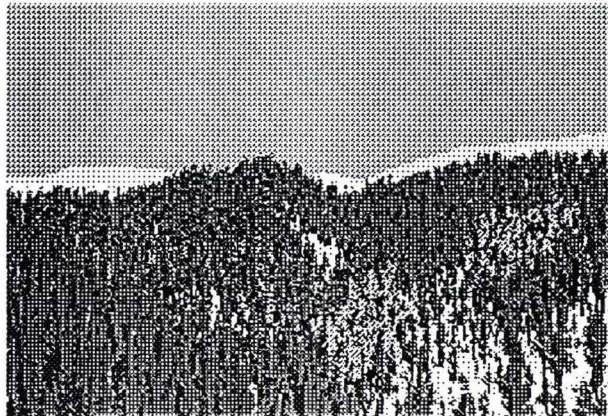
PRESS RETURN TO CONTINUE



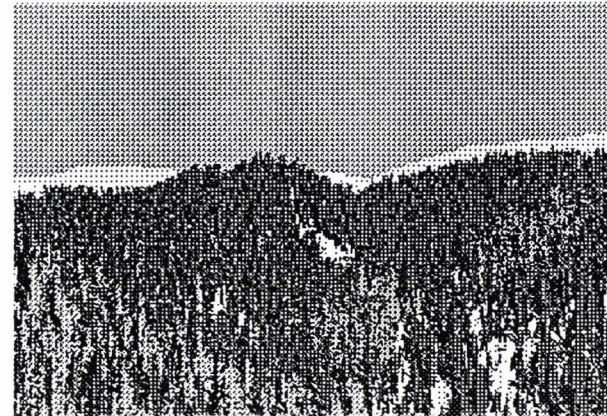
THINNING: 1990



THINNING: 1993



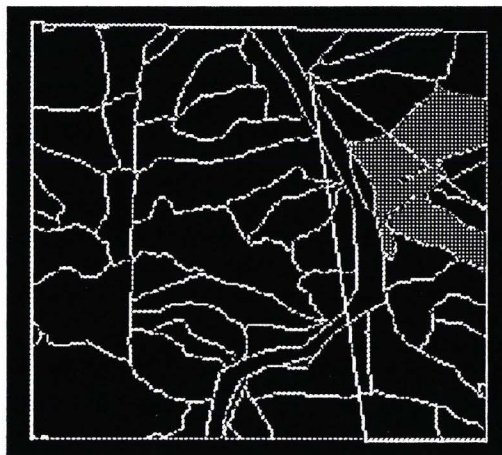
THINNING: 1996



THINNING: 1999

PRESS RETURN TO CONTINUE

CLEARCUT: STANDS SURROUNDING THE OUTBREAK
ARE CLEARCUT.

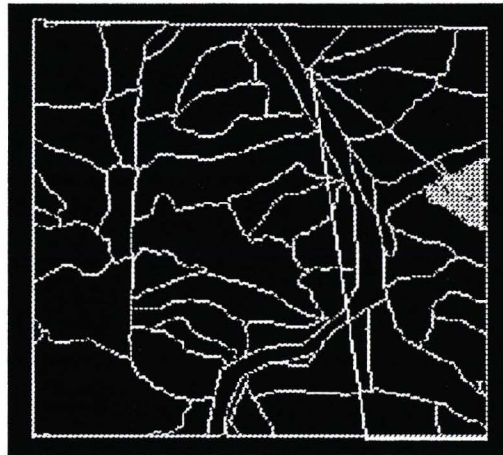


■ STANDS CLEARCUT
----- VIEWSHED
////////// STAND BOUNDARIES

OUTPUT OPTIONS

- 1 EXIT
- 2 DISPLAY SPREADMAP/VIEWSCENE/YEAR
- 3 DISPLAY ALL SPREADMAPS
- 4 DISPLAY ALL VIEW SCENES

SELECT:

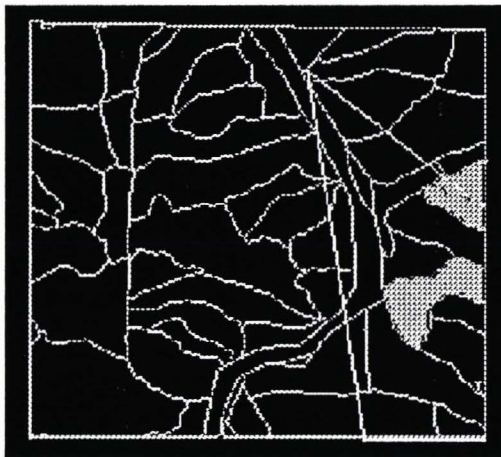


MPB OUTBREAK
VIEWSHED
STAND BOUNDARIES

CLEARCUT: 1990

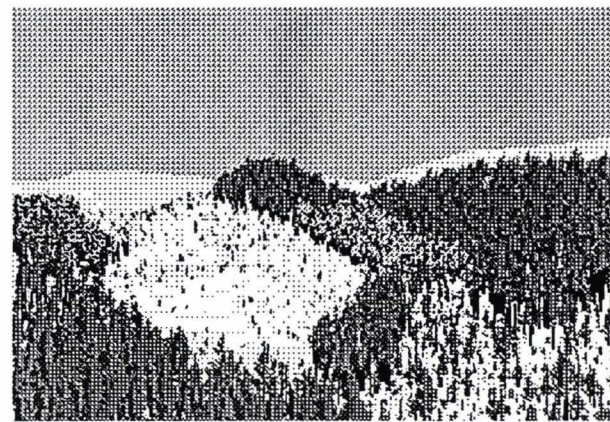


PRESS RETURN TO CONTINUE

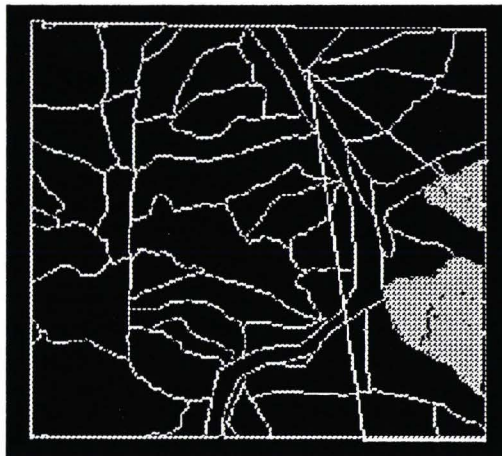


MPB OUTBREAK
VIEWSHED
STAND BOUNDARIES

CLEARCUT: 1993

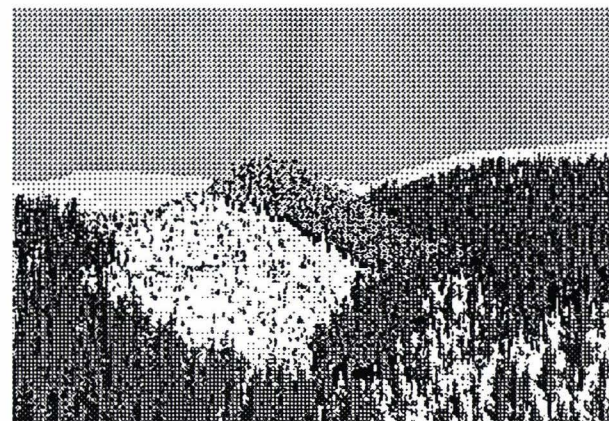


PRESS RETURN TO CONTINUE

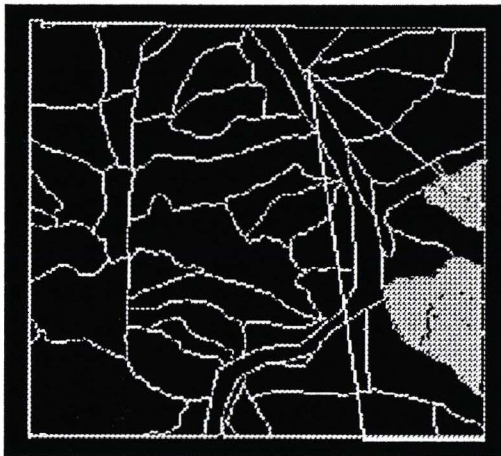


MPB OUTBREAK
VIEWSHED
STAND BOUNDARIES

CLEARCUT: 1996

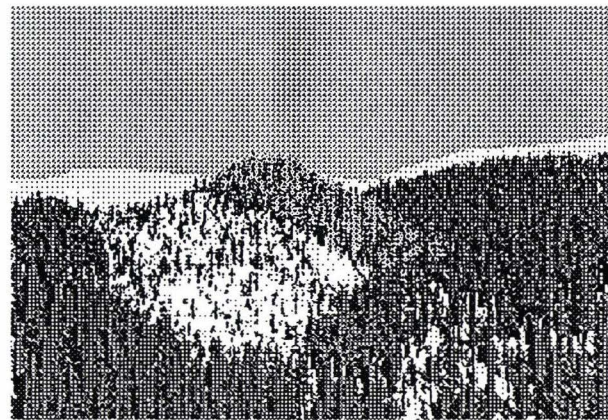


PRESS RETURN TO CONTINUE

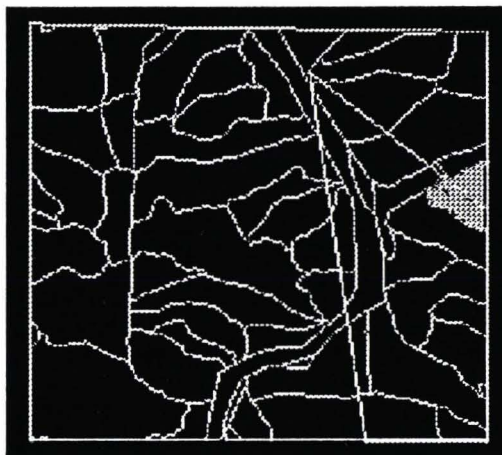


MPB OUTBREAK
VIEWSHED
STAND BOUNDARIES

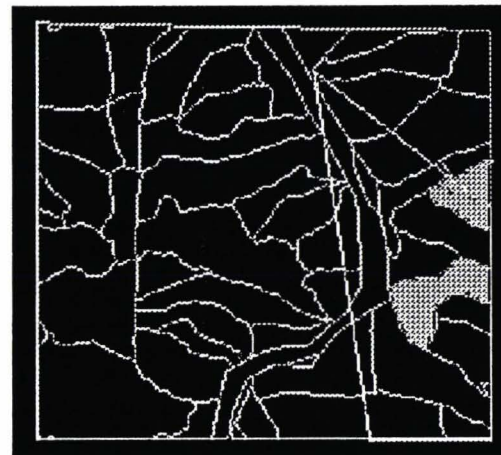
CLEARCUT: 1999



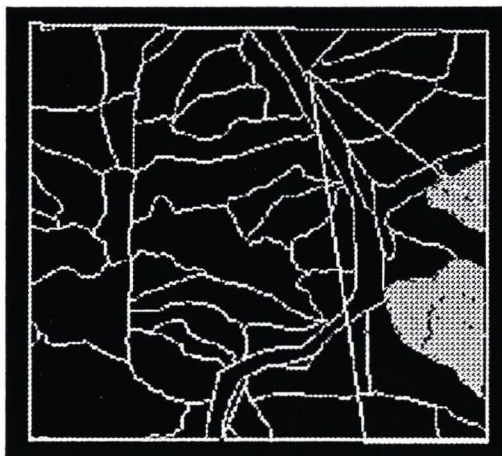
PRESS RETURN TO CONTINUE



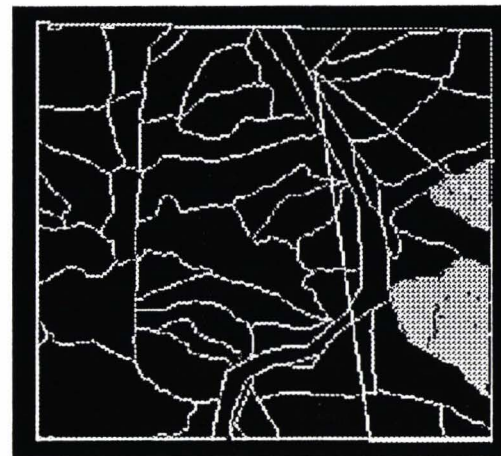
CLEARCUT: 1990



CLEARCUT: 1993

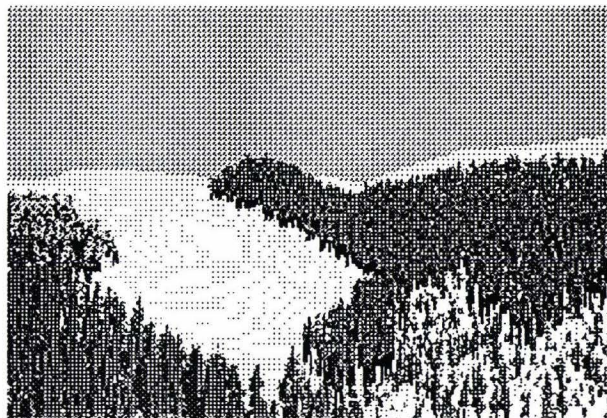


CLEARCUT: 1996

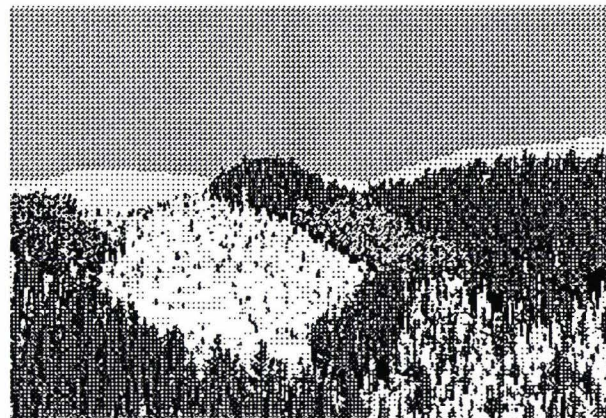


CLEARCUT: 1999

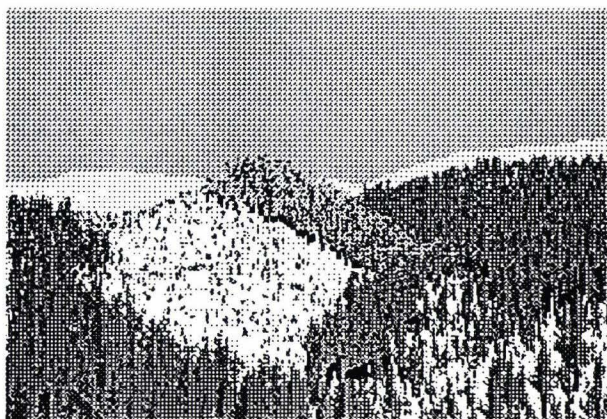
PRESS RETURN TO CONTINUE



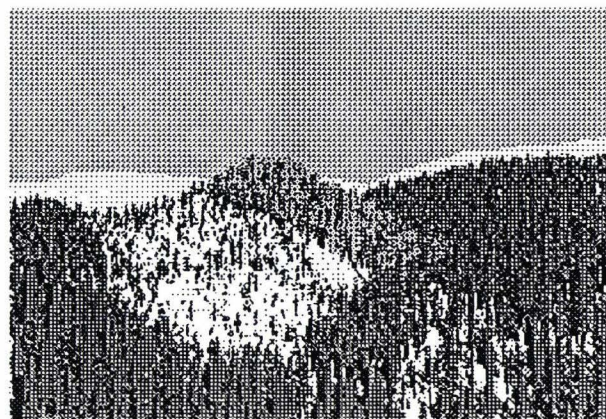
CLEARCUT: 1990



CLEARCUT: 1993



CLEARCUT: 1996



CLEARCUT: 1999

PRESS RETURN TO CONTINUE

TREATMENT COMPARISONS: COMPARE TREATMENTS WITHIN EACH YEAR.

OUTPUT OPTIONS

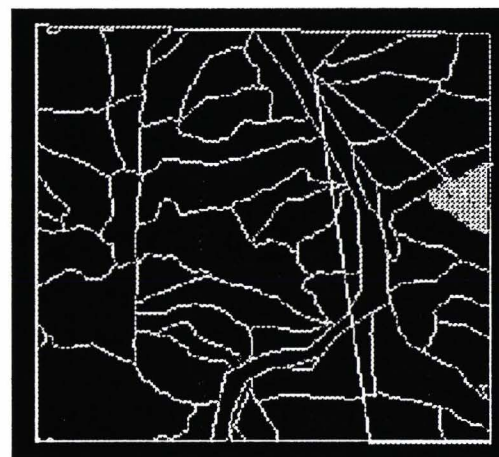
- 1 EXIT
- 2 DISPLAY SPREADMAPS
- 3 DISPLAY VIEW SCENES

SELECT:

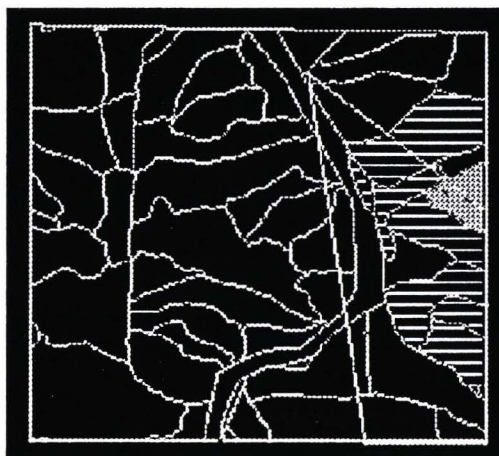
TREATMENT COMPARISONS

1990

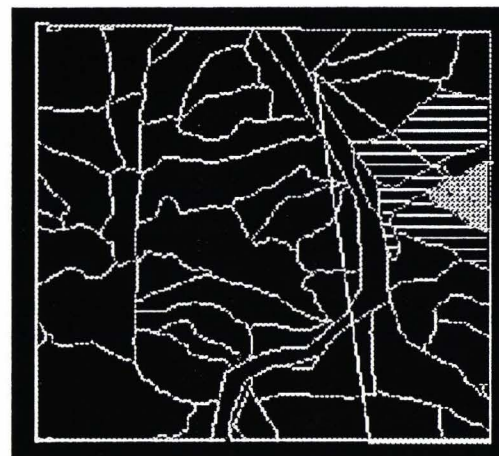
- MPB OUTBREAK
- STANDS TREATED
- VIEWSHED
- STAND BOUNDARIES



NO TREATMENT: 1990



THINNING: 1990

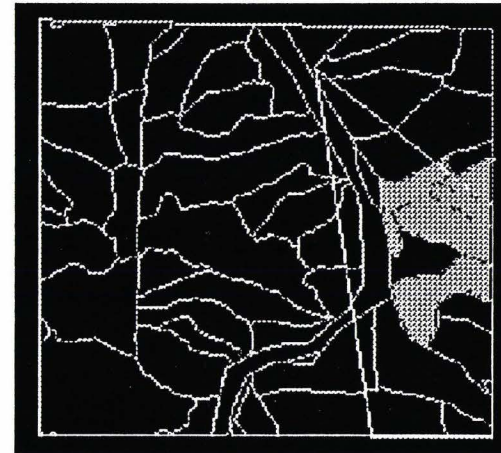


CLEARCUT: 1990

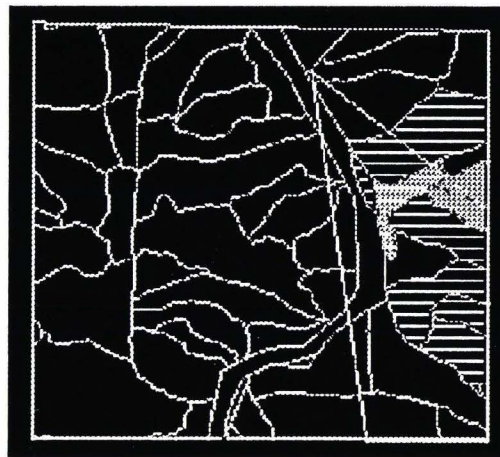
PRESS RETURN TO CONTINUE

TREATMENT COMPARISONS
1993

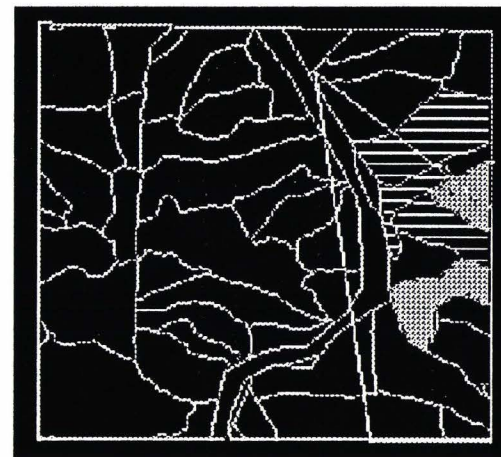
-  MPB OUTBREAK
-  STANDS TREATED
-  VIEWSHED
-  STAND BOUNDARIES



NO TREATMENT: 1993



THINNING: 1993

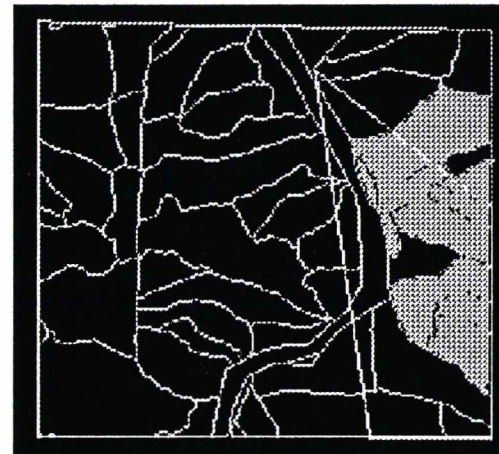


CLEARCUT: 1993

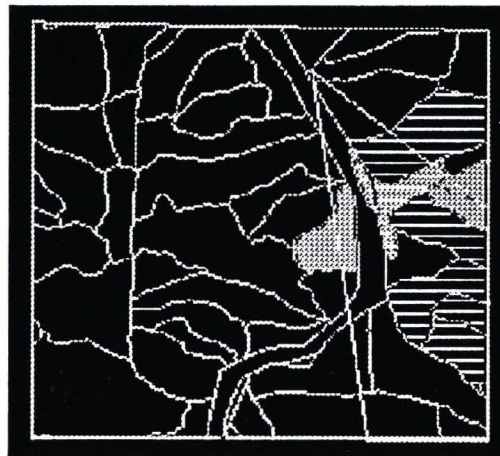
PRESS RETURN TO CONTINUE

TREATMENT COMPARISONS
1996

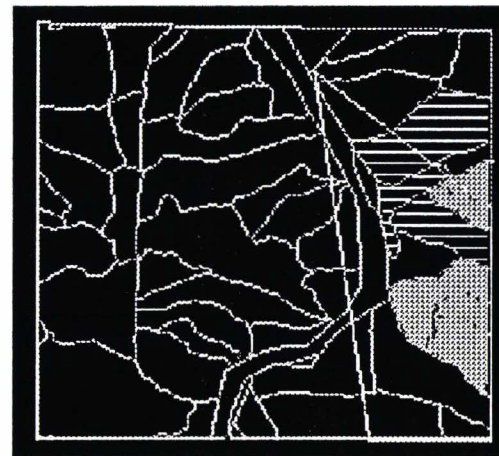
-  MPB OUTBREAK
-  STANDS TREATED
-  VIEWSHED
-  STAND BOUNDARIES



NO TREATMENT: 1996



THINNING: 1996

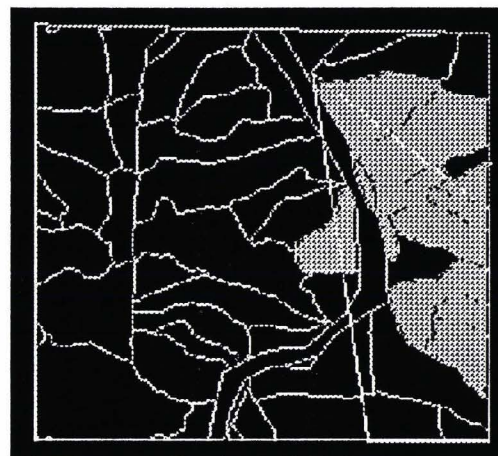


CLEARCUT: 1996

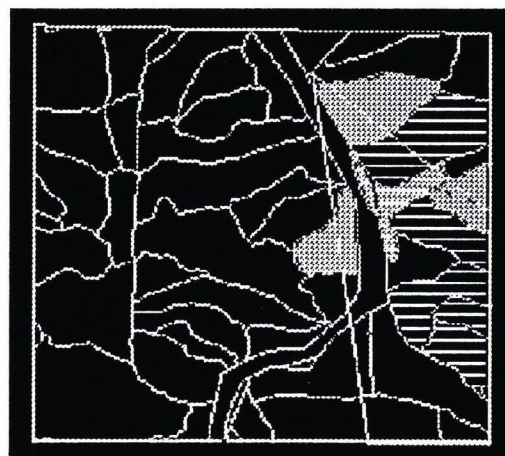
PRESS RETURN TO CONTINUE

TREATMENT COMPARISONS
1999

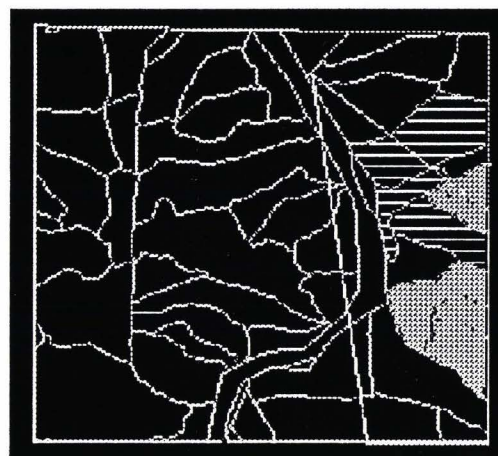
-  MPB OUTBREAK
-  STANDS TREATED
-  VIEWSHED
-  STAND BOUNDARIES



NO TREATMENT: 1999



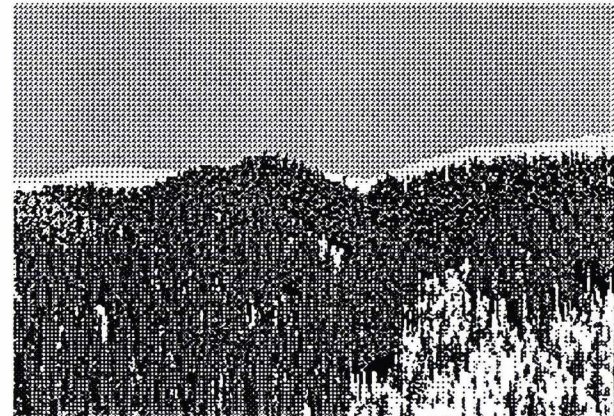
THINNING: 1999



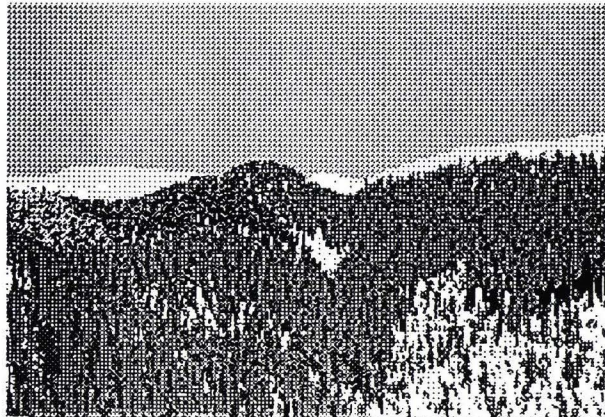
CLEARCUT: 1999

PRESS RETURN TO CONTINUE

TREATMENT COMPARISONS
1990



NO TREATMENT: 1990



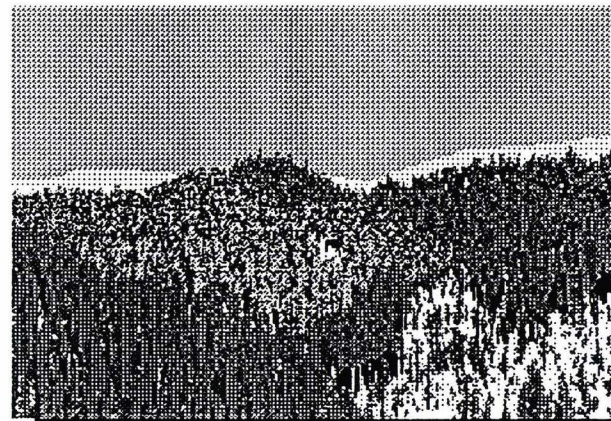
THINNING: 1990



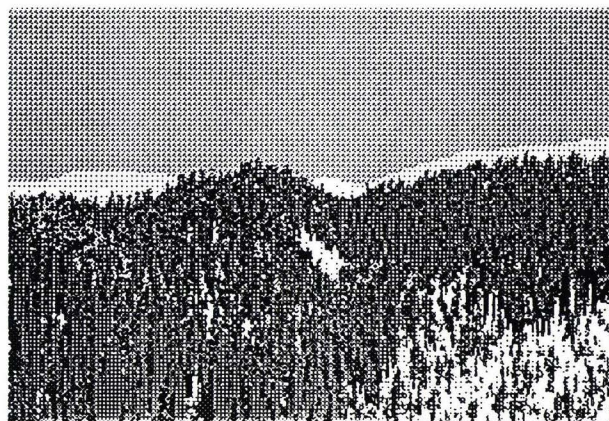
CLEARCUT: 1990

PRESS RETURN TO CONTINUE

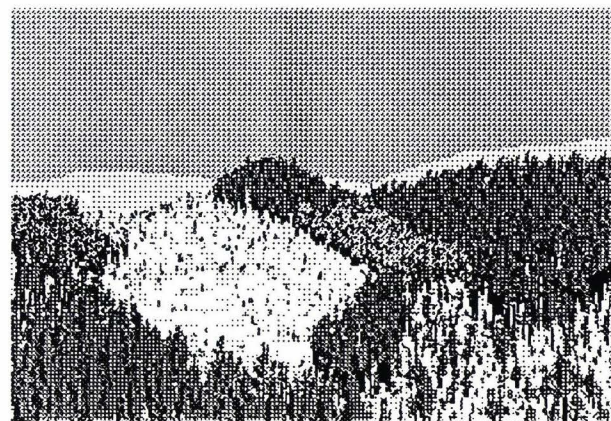
TREATMENT COMPARISONS
1993



NO TREATMENT: 1993



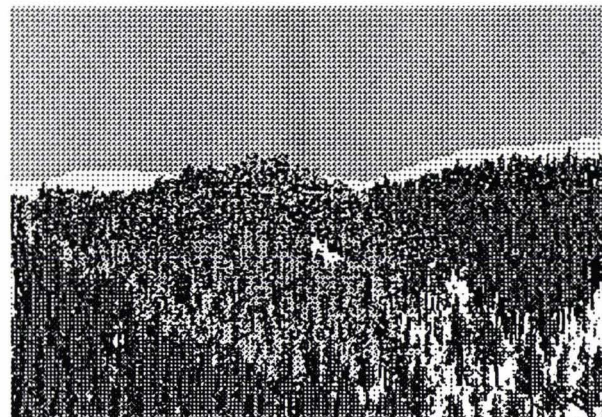
THINNING: 1993



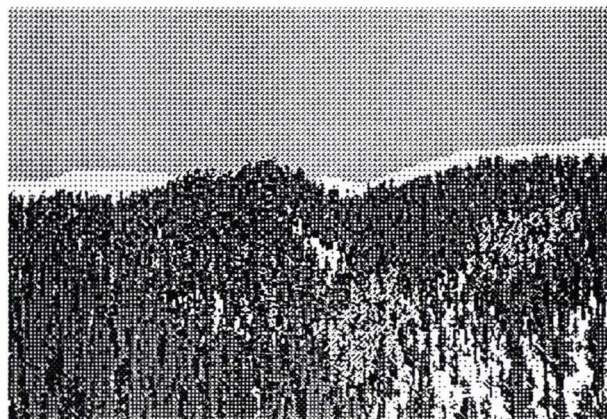
CLEARCUT: 1993

PRESS RETURN TO CONTINUE

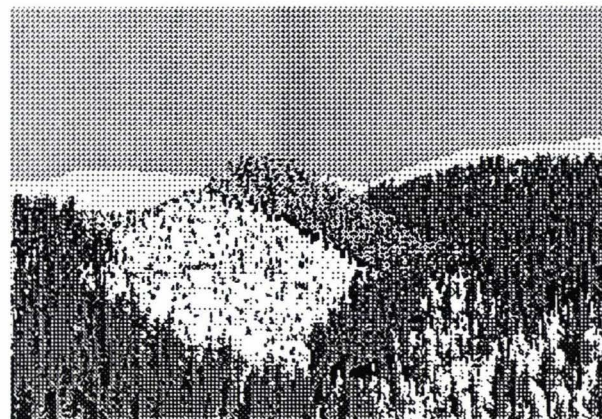
TREATMENT COMPARISONS
1996



NO TREATMENT: 1996



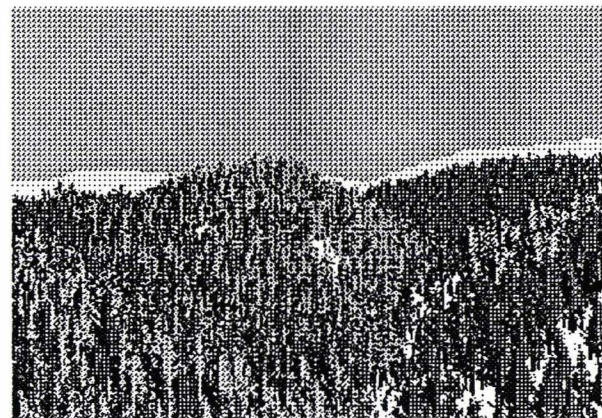
THINNING: 1996



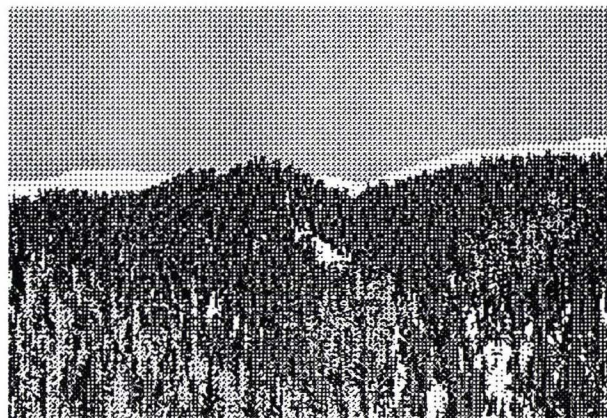
CLEARCUT: 1996

PRESS RETURN TO CONTINUE

TREATMENT COMPARISONS
1999



NO TREATMENT: 1999



THINNING: 1999



CLEARCUT: 1999

PRESS RETURN TO CONTINUE